National Aeronautics and Space Administration
Goddard Institute for Space Studies
New York, N.Y.

NASA Goddard Institute for Space Studies (GISS)
Climate Change Research Initiative (CCRI)
Applied Research STEM Curriculum Unit Plan

Unit Title: Future Temperature Projections

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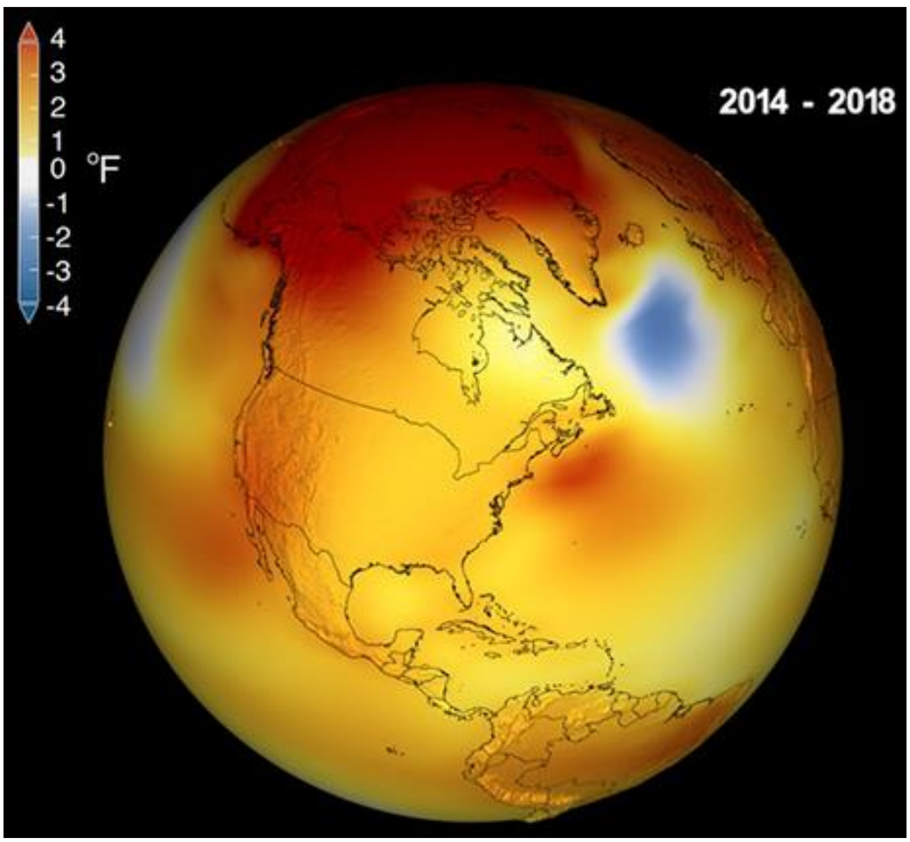
NASA PI / Mentor: Dr. Allegra N. LeGrande
NASA GSFC Office of Education – Code 160



I. Executive Summary

The title of this unit is Future Temperature Projections and will allow students to analyze and evaluate future temperature projections up to the year 2100 from the NASA Goddard Institute for Space Studies Global Climate Model called GISS-ModelE2. The NASA GISS ModelE2 and other climate models simulate present day climate based on knowledge of how the heat and energy move around the earth and observations of the radiative forcing of the entire system. Currently (as of 2011), the human-caused, or anthropogenic, radiative forcing of the climate system is ~2.3 W/m^2 (watts per meter-squared), with about a third of that not yet realized as temperature change. To estimate future climate, the radiative forcing for the future must first be estimated; this is accomplished through Representative Concentration Pathways (RCP) scenarios. These RCP scenarios are future economic and development forecasts that estimate global output of greenhouse gases. Each of the four RCP scenarios differ by the amount of greenhouse gas radiative forcing applied to the model simulation. In short, a positive greenhouse gas radiative forcing means greenhouse gases are causing Earth to receive more incoming solar radiation (insolation) than it is radiating back towards space. All RCP scenarios are based on positive greenhouse gas radiative forcing values. In this unit, the students will be engaging with the RCP 2.6, RCP 4.5, and RCP 8.5 scenarios, which correspond to greenhouse gas radiative forcings of 2.6 W/m^2, 4.5 W/m^2, and 8.5 W/m^2, respectively.

Climate scientists use RCP scenarios in their future climate change projection models because the future state of Earth's climate system is dependent on the amount of greenhouse gas emissions. It is uncertain how much the world can reduce greenhouse gas emissions and the different RCP scenarios account for the possible pathways the Earth's climate could develop through the year 2100. It is essential for the students to understand that changes to temperature patterns in the future can change if the future greenhouse gas emissions change. This unit allows the students to evaluate how the RCP 4.5 and RCP 8.5 scenarios compare to the best-case scenario (smallest change from the historic period of the last 150 years) of RCP 2.6 in terms of global temperature projections. As Earth's climate continues to change, it is essential for people to understand how temperature is expected to change across the world and how the changes are dependent on the amount of future greenhouse gas emissions. When people are able to see the future impacts of climate change, they are more likely to take action and help reduce the amount of greenhouse gas emissions to keep future projections closer to the RCP 2.6 scenario.

II. Introduction Goals and Overview of Unit

The title of this unit is Future Temperature Projections and will allow students to analyze and evaluate future temperature projections up to the year 2100 from the NASA Goddard Institute for Space Studies Global Climate Model called GISS-ModelE2. This unit should be completed after students learn about factors that influence climate, such as Earth's energy budget and greenhouse gases emissions, and the impacts of climate change. The NASA GISS ModelE2 and other climate models simulate present day climate based on knowledge of how the heat and energy move around the earth and observations of the radiative forcing of the entire system. To estimate future climate, the radiative forcing for the future must first be estimated; this is accomplished through Representative Concentration Pathways (RCP) scenarios. These RCP scenarios are future economic and development forecasts that estimate global output of greenhouse gases. Each of the four RCP scenarios differ by the amount of greenhouse gas radiative forcing applied to the model simulation. In short, a positive greenhouse gas radiative forcing means greenhouse gases are causing Earth to receive more incoming solar radiation (insolation) than it is radiating back towards space. All RCP scenarios are based on positive greenhouse gas radiative forcing values. In this unit, the students will be engaging with the RCP 2.6, RCP 4.5, and RCP 8.5 scenarios, which correspond to greenhouse gas radiative forcings of 2.6 W/m^2, 4.5 W/m^2, and 8.5 W/m^2, respectively.

The students will begin the unit in lesson #1 reading a science journal authored by NASA GISS scientist Dr. Larissa Nazarenko and others titled "Future Climate Change Under RCP Emission Scenarios with GISS ModelE2". Students will be directed to section 3 of the article titled Representative Concentration Pathway (RCP) Experiments. As the students read this section, they will complete a graphic organizer to learn how the RCP scenarios and their respective greenhouse gas radiative forcings are used to simulate future climate change. In this same lesson, the students will learn how to effectively compare simulated outcomes from the RCP scenarios by analyzing difference, or anomaly, maps that result from subtracting the output from two scenarios that are being compared. In this unit, all RCP scenarios are compared to the baseline RCP 2.6 scenario. This part of the lesson is crucial for student understanding in lessons #2 and #3 of the unit. Finally, at the end of lesson #1 the students will lead a whole class discussion about the RCP scenario they believe will become our reality by the year 2100. This allows students to build on prior knowledge to make predictions about Earth's future based on the current state of our climate and actions of our society.

In lesson #2, the students will download the RCP 2.6, 4.5, and 8.5 temperature projection output from the NASA GISS ModelE2 and learn how to analyze the contents of the output in RStudio. Climate-related data and model simulations are often stored in the data format called netCDF (files that end in .nc), and the lesson begins with a guide that teaches students how to work with netCDF data in RStudio. The guide shows students how to compare RCP scenarios by subtracting the output, resulting in RCP 8.5 – 2.6 and RCP 4.5 – 2.6 scenarios. The students will ultimately learn how to calculate monthly averages in three different 30-year intervals from 2011 to 2100 for the RCP 8.5 – 2.6 and RCP 4.5 – 2.6 scenarios for New York City. The goal is for the students to learn how temperature projections are expected to change as we progress into the future up to 2100.

In order to successfully complete lesson #3, students need to apply the skills and content they acquired in lesson #2. In lesson #3, the students will be working in groups to evaluate monthly temperature projections for three different 30-year intervals for the RCP 8.5 – 2.6 and RCP 4.5 – 2.6 scenarios for another city around the world. Students will be assigned a city based on climate parameters such as proximity to the Intertropical Convergence Zone (ITCZ), proximity to a desert, influence of the Indian Monsoon, influence of the El Niño Southern Oscillation (ENSO), and influence of the North Atlantic Oscillation (NAO). The students will prepare and present an oral presentation that teaches the class about the climate of their city, and how climate change is expected to impact their city based on the temperature projections from the NASA GISS ModelE2.

There is highlighted text throughout the unit intended for specific reasons. The reasons are described here:

- Yellow means the text provides essential information for students or teachers
- Blue means the following text is for teachers only
- Purple means the text is related to Functions.R (this will be introduced in lesson #2)

III. Educator Biography

Nicole Dulaney – Earth Science & STEM Educator
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Nicole Dulaney has been a New York City Department of Education Earth Science teacher at Hillcrest High School in Jamaica, Queens since September 2013. She was also a Math *for* America Early Career Fellow from 2016 to 2019. As of September 2019, Nicole will be teaching Earth Science in the Tuckahoe Union Free School District (UFSD).

Nicole's interest in STEM education can be traced back to her childhood, when she would often track East Coast Winter Storms. She is grateful to have a career in a field that merges her passion of STEM content and education, and she looks forward to empowering the next generation of STEM leaders. Nicole earned a Bachelor of Science in Atmospheric Science *cum laude* from Cornell University and a Master of Arts in Adolescent Education from Hunter College.

Over her career, Nicole has participated in two research programs for STEM educators. During the summers of 2014 and 2015, she participated in the Columbia University Summer Research Program for Science Teachers. From 2015 to 2018, Nicole worked as an associate researcher with the NASA GISS Climate Change Research Initiative (CCRI). Through her research experience with CCRI, Nicole created a STEM Earth Science research class at Hillcrest High School. The course began in September 2016 and introduced students to Earth's climate system. In this course, students learn about past, present and future climate change; the course heavily leverages on NASA resources. Students end the year engaging in a group-based research project about a topic related to climate change.

Nicole looks forward to enhancing the STEM offerings and opportunities for students in the Tuckahoe UFSD when she begins teaching at Tuckahoe Middle School in the fall 2019.

IV. Table of Contents

Clicking on each component of the Table of Contents will bring you directly to the location in the document.

V. NASA Education Resources Utilized in Unit

A) Resources

1. Future Climate Change Under RCP Emission Scenarios with GISS ModelE2 (Lesson #1)
This NASA resource is a science journal article from 2015 by Dr. Larissa Nazarenko and other NASA GISS authors such as Dr. Gavin Schmidt and Dr. Allegra LeGrande. The article discusses the future projections from the year 2006 to 2100 of the NASA GISS ModelE2 through the different Representative Concentration Pathway (RCP) scenarios. The students will utilize section 3 of this resource to learn about the different RCP scenarios that are based on different greenhouse gas radiative forcing values.
This is the link to the Nazarenko et al., 2015 research paper

2. GISS ModelE2 future climate change projection simulations (Lessons #2 and #3)
This NASA resource allows students to download future temperature projection model output from the NASA GISS ModelE2 from the year 2006 to 2100. The exact link to the model output is provided rather than a descriptive link because the link needs to be copied and pasted into a browser to work.
ftp://gdo-dcp.ucllnl.org/pub/dcp/archive/cmip5/global_mon/BCSD/giss-e2-r/

3. Forcings in the GISS Climate Model (Lesson #1)
This NASA resource is in the For Further Exploration section in Lesson #1. The lesson is mainly based on forcings from carbon dioxide emissions and this resource allows students and teachers to expand their knowledge on other forcings in the model. Link to information about forcings in the GISS climate model

4. NASA Global Climate Change Website (Lessons #1 and #3)
This NASA resource allows students to explore background content regarding evidence, causes, effects, and solutions to climate change. If students lack the prior knowledge needed for this unit, teachers can utilize this resource. Link to the NASA global climate change website

B) Data Visualization and Analysis Activity

Lesson #1 – The visualization activity in this lesson is based on the world maps students are asked to analyze to learn how to properly compare model output from two different RCP scenarios. Students are given maps of temperature projections for December 2100 for all RCP scenarios and are asked questions about each map. Students are then asked to answer the same analysis questions using difference maps of the RCP 8.5 – 2.6, RCP 6.0 – 2.6, and RCP 4.5 – 2.6 scenarios. The goal is to show students that subtracting the RCP projection output allows for an easier and more accurate analysis of the different RCP scenarios.

Lesson #2 – The activity in this lesson is based on the students using the R programming language to read the contents of the netCDF model output from the NASA GISS ModelE2. Students will be learning how to create average monthly temperature projection graphs for three different 30-year intervals from 2011 to 2100 to show how temperature projections are expected to change for New York City.

Lesson #3 – The activity in this lesson is based on the students using the skills they developed in Lesson #2 to create similar temperature projection graphs in RStudio for different cities around the world.

C) NASA Mission Alignment

This unit plan is entirely dependent on future simulated projections from the NASA GISS ModelE2 through the Representative Concentration Pathway (RCP)scenarios. The NASA GISS ModelE2 was developed under the leadership of NASA GISS director Dr. Gavin Schmidt and has been used in simulations with the Coupled Model Intercomparison Project Phase 5 (CMIP5). The CMIP5 simulations provided the basis for the future climate estimations in the Intergovernmental Panel on Climate Change, Phase 5 (Taylor, Stouffer, & Meehl, 2012). The goal of analyzing the output from the GISS ModelE2 with the RCP scenarios is to determine how future greenhouse gas emissions will influence the climate through the year 2100 and to understand the range of potential outcomes if current greenhouse gas emission rates are changed. There is a large amount of uncertainty surrounding how much the world can reduce future greenhouse gas emissions, and it is essential for global climate models such as the GISS ModelE2 to account for different emission scenarios when making future projections.

D) NASA 2018 Strategic Objectives Alignment

This unit plan relates directly to the NASA 2018 Strategic Goal #1 – Expand Human Knowledge Through New Scientific Discoveries. NASA's missions allow for the public to view and analyze data such as model output from the GISS ModelE2. In each lesson, students are directly engaging with future climate projection simulations from the model to evaluate how temperature projections are expected to change overtime. With this model output, the unit also allows students to expand their knowledge of how temperature projections are dependent on different greenhouse gas emission scenarios and how climate change will impact multiple regions of the world in different ways. Under Strategic Goal #1, this lesson also aligns well with Strategic Objective 1.1 – Understand the Sun, Earth, Solar System, and Universe. Throughout the unit, the students are learning more about Earth's climate system and future climate change projections through analysis of output from the GISS ModelE2. Students are also able to use the output to help improve life on Earth by learning how projections can be impacted by greenhouse gas emissions and which regions of the world are most vulnerable to changes in temperature. Finally, this unit is also aligned to Strategic Objective 3.3 – Inspire and Educate the Public in Aeronautics, Space, and Science, as the nature of this unit is to educate society about climate change.

E) NASA Office of STEM Engagement Objectives Alignment

This unit plan is also aligned with the NASA Office of STEM Engagement objectives, specifically,

- 1.1 – Students contribute to NASA's endeavors in exploration and discovery.
- 2.1 – Students, including those from underrepresented and underserved communities, explore and pursue STEM pathways through authentic learning experiences and research opportunities with NASA's people and work.

Throughout the unit, students are exploring the contents of simulated model output from the NASA GISS ModelE2, allowing students the opportunity to engage in a NASA endeavor with regard to future climate change projections. Through all lessons, students have the opportunity to pursue STEM pathways by conducting data analysis similar to the analyses performed daily by NASA researchers.

VI. Unit Pre & Post Standards-Based Assessment

Pre & Post-Unit Assessment: Earth's Energy Budget

In order to truly measure student growth after the completion of the unit, the pre-assessment will be the same as the post-assessment.

The pre and post-unit assessment is based on New York State Earth Science Regents questions and standards. Since students in New York State taking part in these lessons are also likely taking Regents Earth Science, students need to be familiar with answering Regents-style questions. The following New York State Earth Science standards are assessed:

2.2a - Insolation (incoming solar radiation) heats Earth's surface and atmosphere unequally due to variations in:

- the intensity caused by differences in atmospheric transparency and angle of incidence which vary with time of day, latitude, and season
- characteristics of the materials absorbing the energy such as color, texture, transparency, state of matter, and specific heat
- duration, which varies with seasons and latitude.

6.1 - Identifying patterns of change is necessary for making predictions about future behavior and conditions.

______**1.** Most scientists infer that a major factor in the increased rate of melting of Earth's glaciers is

(1) a decrease in the output of energy from the Sun
(2) a decrease in Earth's atmospheric transparency
(3) an increase in Earth's orbital distance from the Sun
(4) an increase in carbon dioxide in Earth's atmosphere

______**2.** Which list contains three major greenhouse gases found in Earth's atmosphere?

(1) carbon dioxide, methane, and water vapor
(2) carbon dioxide, oxygen, and nitrogen
(3) hydrogen, oxygen, and methane
(4) hydrogen, water vapor, and nitrogen

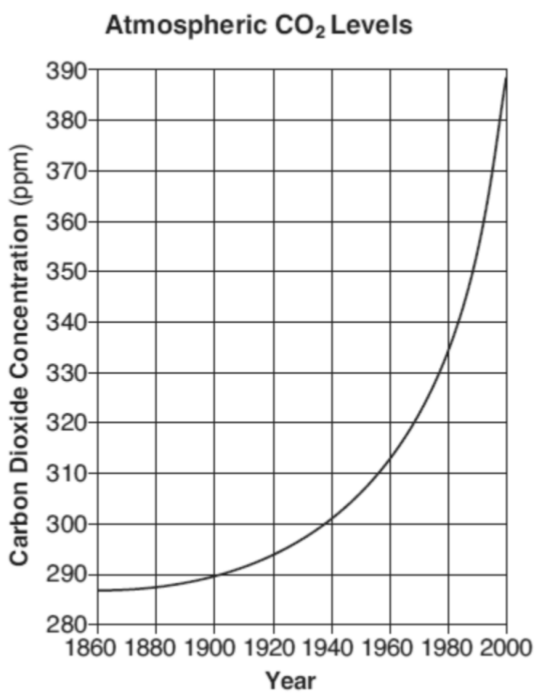
______**3.** Most scientists infer that increasing levels of carbon dioxide in Earth's atmosphere are contributing to

(1) decreased thickness of the troposphere
(2) depletion of ozone
(3) increased absorption of ultraviolet radiation
(4) increased global temperatures

______**4.** Which event is inferred by most scientists to be responsible for a climate change that has recently led to a *decrease* in the size of most glaciers?

(1) a decrease in the rate of divergence of lithospheric plates along a mid-ocean ridge
(2) a decrease in the amount of insolation reaching Earth's surface
(3) an increase in the amount of greenhouse gases in Earth's atmosphere
(4) an increase in the amount of vegetative cover in the tropics

______**5.** The graph below shows changes in carbon dioxide concentrations in Earth's atmosphere over a 140-year period. Carbon dioxide concentrations are shown in parts per million (ppm).



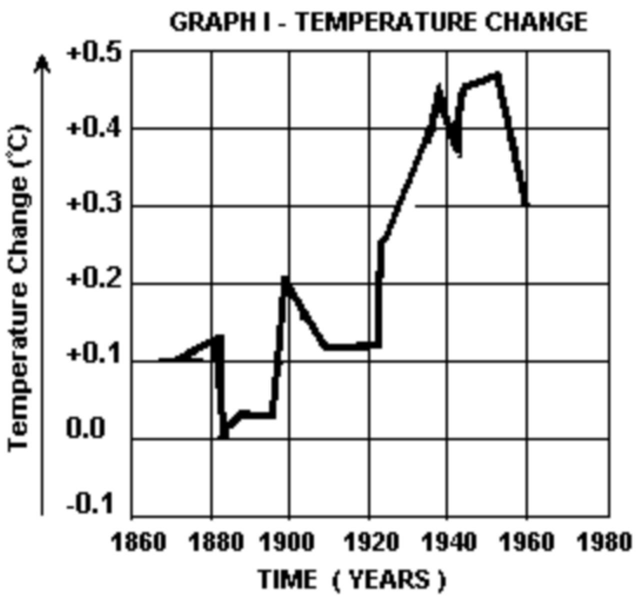
This significant change in CO_2 concentration is most likely caused by

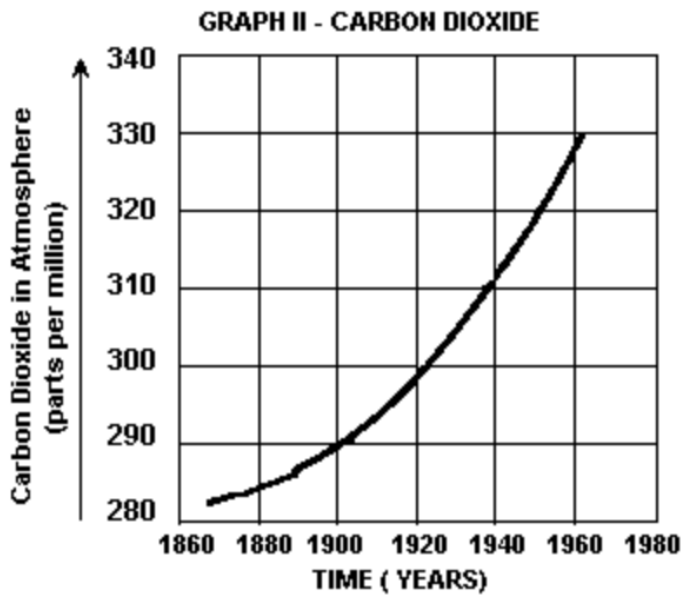
(1) decreased cloud cover, and is predicted to decrease average global temperatures
(2) decreased volcanic activity, and is predicted to increase average global temperatures
(3) increased use of fossil fuels, and is predicted to increase average global temperatures
(4) increased El Niño activity, and is predicted to decrease average global temperatures

______**6.** The process of developing and implementing environmental conservation programs is most dependent on

(1) the availability of the most advanced technology
(2) the Earth's ability to restore itself
(3) public awareness and cooperation
(4) stricter environmental laws

Use the graphs below to answer questions 7 - 10. Graph I shows the average temperature change on Earth between the years 1870 and 1955. Graph II shows the amount of carbon dioxide in the atmosphere between the years 1870 and 1962.





______**7.** What was the approximate overall change in the carbon dioxide content between 1900 and 1962?

(1) 330 parts per million
(2) 290 parts per million
(3) 40 parts per million
(4) 0.4 parts per million

______**8.** If the trend shown in graph II continued into 1980, the amount of carbon dioxide in the atmosphere in 1980 was probably

(1) less than 30 parts per million
(2) between 100 and 280 parts per million
(3) between 300 and 320 parts per million
(4) greater than 340 parts per million

______**9.** Which statement best accounts for the relationship between the carbon dioxide and temperature change data shown by the graphs?

(1) Carbon dioxide is a good absorber of infrared radiation.
(2) Carbon dioxide is a poor absorber of infrared radiation.
(3) Temperature decreases usually occur when the carbon dioxide content of the atmosphere increases.
(4) Temperature changes do not usually occur when the carbon dioxide content of the atmosphere increases.

______**10.** Which is the best interpretation that can be made from the graphs for the period between 1870 and 1955?

(1) The amount of carbon dioxide in the atmosphere has increased steadily, and the temperature change on Earth has shown an overall increase.
(2) The amount of carbon dioxide in the atmosphere and the temperature change on Earth have increased at a steady rate.
(3) The amount of carbon dioxide in the atmosphere has decreased steadily, and the temperature change on Earth has shown an overall decrease.
(4) The amount of carbon dioxide in the atmosphere has decreased at a steady rate, causing a varying change in temperature on Earth.

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NASA Goddard Institute for Space Studies (GISS)
Climate Change Research Initiative (CCRI)
Applied Research STEM Curriculum Unit Portfolio

Unit Title: Future Temperature Projections
Lesson #1 Title: RCP Projection Scenarios
NASA STEM Educator / Associate Researcher: Nicole Dulaney
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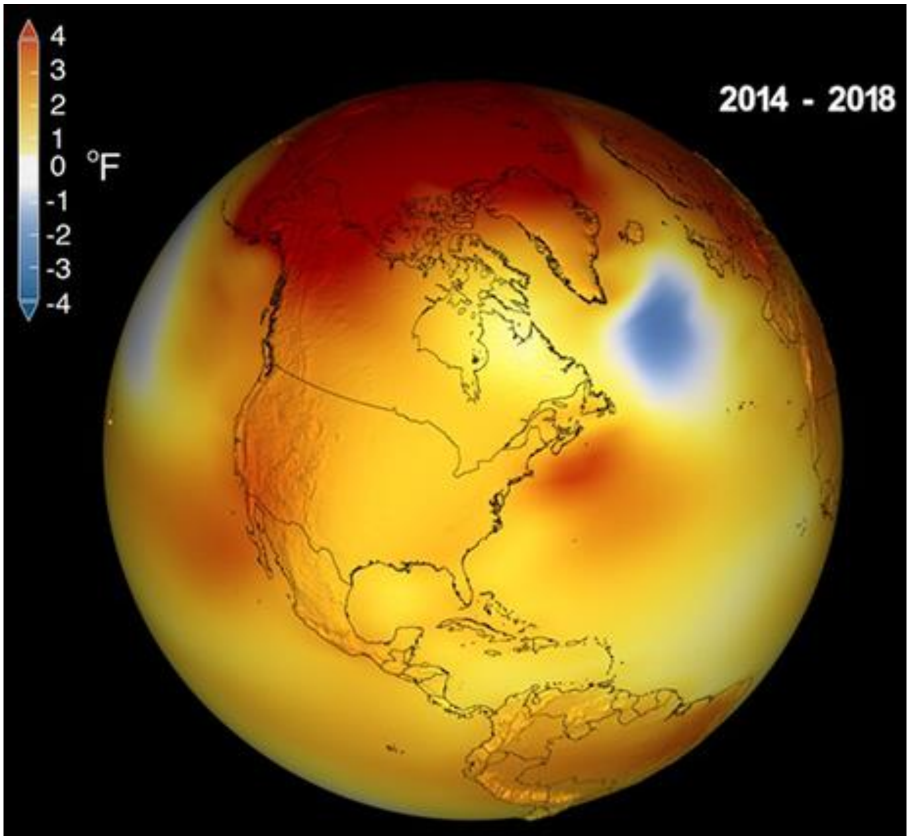


VII. Lesson #1: RCP Projection Scenarios

A. Summary and Goals of Lesson

The goal of this lesson is for the students to learn how global climate models such as the NASA GISS ModelE2 use Representative Concentration Pathway (RCP) scenarios to predict future climate patterns, such as temperature and precipitation projections, which are based on greenhouse gas radiative forcings. A radiative forcing is defined as the difference between incoming solar radiation (insolation) absorbed by the Earth and energy sent back towards space. The students will learn about greenhouse gas radiative forcings and the RCP scenarios when they read a section of a paper by Dr. Larissa Nazarenko and other GISS authors titled Future Climate Change Under RCP Emission Scenarios with GISS ModelE2. As the students read section 3 of the paper titled Representative Concentration Pathway (RCP) Experiments, they will complete a graphic organizer to learn about the RCP 2.6, 4.5, 6.0, and 8.5 scenarios. These scenarios are based on the different greenhouse gas radiative forcings Earth could experience in the future. The higher RCP scenario predicts greater greenhouse gas emissions in the future, which leads to a greater radiative forcing since more outgoing longwave radiation will be absorbed in the atmosphere.

After the students learn about the RCP scenarios, the students will learn how to effectively compare RCP projection model output. The students will first be provided with maps that show temperature projection simulations for December 2100 for the RCP 2.6, 4.5, 6.0, and 8.5 scenarios. Students will be asked a series of questions about the locations that are expected to experience the greatest temperature out of all scenarios. The students will then be given difference maps that show the December 2100 temperature projections for the RCP 8.5 – 2.6, RCP 6.0 – 2.6, and RCP 4.5 – 2.6 scenarios. The RCP 2.6 scenario is used as a comparative baseline to the other RCP scenarios. The students will then be asked the same series of questions as the ones for the RCP 2.6, 4.5, 6.0, and 8.5 scenarios. This will allow the students to see that analyzing the difference between model output is more effective for comparing different RCP scenarios.

Finally, the lesson ends with the students leading a whole class discussion about the RCP scenario they believe will become our reality by the year 2100. This allows students to build on prior knowledge to make predictions about Earth's future based on the current state of our climate and actions of our society.

B. Table of Contents for lesson

C. 5 E Lesson Model Template

STEM Earth Science Research

Unit: Future Temperature Projections **Topic**: RCP Projection Scenarios

Prior Learning: For successful completion of this lesson, the students should have knowledge of how increasing or decreasing greenhouse gases plays a role in impacting Earth's climate. Students should know that greenhouse gases trap outgoing longwave radiation (infrared energy) and can influence temperature at Earth's surface. The students should also have knowledge of Earth's energy budget and how the relationship between incoming and outgoing energy can influence Earth's average temperature. If students need more information about the role greenhouse gases have in climate change, please visit this link to NASA resource about the causes of climate change. This resource will also remind students about the evidence of climate change and the impacts.

In this lesson, the students will learn about the Representative Concentration Pathways (RCP) projection scenarios by reading a section of a published research paper from Dr. Larissa Nazarenko and other GISS scientists titled Future Climate Change Under RCP Emission Scenarios with GISS ModelE2. The students will learn about the four different RCP scenarios by completing a graphic organizer as they read the research paper. The goal is for the students to learn how each RCP scenario directly impacts Earth's energy budget. Next, students will learn how to effectively compare simulated outcomes between the RCP scenarios by analyzing difference maps that result from subtracting model output from the two scenarios that are being compared. Finally, the students will utilize prior knowledge about greenhouse gases and climate change to engage in a whole-class student-lead discussion about the RCP scenario they believe will be our reality by the year 2100.

Warm Up Activity (Pre-Assessment):

1. Predict how decreasing greenhouse gas concentrations will influence temperature at the surface of the Earth. Explain your prediction using prior knowledge of greenhouse gases and outgoing infrared radiation.

2. Predict how increasing greenhouse gas concentrations will influence temperature at the surface of the Earth. Explain your prediction using prior knowledge of greenhouse gases and outgoing infrared radiation.

Aim: How can scientists make predictions related to changes in climate in the future?

New York State Standards:

2.2a - Insolation (incoming solar radiation) heats Earth's surface and atmosphere unequally due to variations in:
- the intensity caused by differences in atmospheric transparency and angle of incidence which vary with time of day, latitude, and season
- characteristics of the materials absorbing the energy such as color, texture, transparency, state of matter, and specific heat
- duration, which varies with seasons and latitude.

6.1 - Identifying patterns of change is necessary for making predictions about future behavior and conditions.

Next Generation Science Standards:

HS - ESS2-4 - Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate.

HS - ESS3-5 - Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth systems.

Common Core State Standards:

CCSS: 9-10.RST.2 - Determine the central ideas or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text.

CCSS: 9-10.RST.7 - Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem.

NASA System Engineering Behavior:
Technical Acumen:
1a. Possesses Technical Competence and Has Comprehensive Previous Experience
1b. Learns from Successes and Failures
Problem Solving & Systems Thinking:
2a. Thinks Systematically
2b. Possess Creativity and Problem-Solving Abilities

Performance Objective: Students will be able to differentiate between the four Representative Concentration Pathways (RCP) scenarios used for future climate projections in the GISS ModelE2 by reading a section of a published research paper by Nazarenko et al., 2015 titled Future Climate Change Under RCP Emission Scenarios with GISS ModelE2 and completing a graphic organizer.

Students will be able to determine how to effectively compare simulated outcomes from the RCP scenarios by evaluating two Figures and answering questions that have the students compare temperature projections from the RCP 4.5, 6.0, and 8.5 scenarios to the RCP 2.6 scenario.

Students will be able to predict which RCP scenario will be our reality by the year 2100 by preparing for and engaging in a whole-class student-lead discussion based on the prompt: ***Which RCP scenario do you think will be our reality by the year 2100?***

Materials: NASA GISS ModelE2 climate projection simulations; NASA GISS Panoply Software

Links to electronic sources are provided below:

- Link to NASA resource about the causes of climate change
- Link to Nazarenko et al., 2015 paper
- GISS ModelE2 Simulated Outcomes: ftp://gdo-dcp.ucllnl.org/pub/dcp/archive/cmip5/global_mon/BCSD/giss-e2-r/
    - The link above cannot be a descriptive link because it must be copied and pasted exactly as is into a browser.

- Link to resource the from the Texas Education Agency the discussion rubric in lesson is adapted from

Vocabulary: Greenhouse gases; Radiative Forcings; Outgoing longwave energy (infrared)

Anticipatory Opening: Discuss with the students how temperatures on Earth would be different if we were to increase or decrease the amount of greenhouse gases in the atmosphere. Then, discuss with the students how climate models can account for changing greenhouse gas concentrations through Representative Concentration Pathways (RCPs).

Development of the Lesson: Approximate Five-Day Lesson (Five 50-minute periods).

What the teacher does	What the student does	Time
1. Write down the Warm Up Activity, Aim, and the HW on the blackboard.		
2. Circulate the room while the students complete the Warm Up Activity questions. Determine how much prior knowledge the students have about greenhouse gases and the amount of outgoing longwave radiation. The questions will also assess student's ability to predict how changing concentrations will influence temperature patterns on Earth. If students need more information about the causes of climate change and the role of greenhouse gases, teachers can utilize this link to NASA resource about the causes of climate change. ***Assessment Opportunity #1 (Student prior knowledge from previous units)***	The students answer the Warm Up Activity questions in their notebooks to determine how much prior knowledge they have about greenhouse gases and the amount of outgoing longwave radiation. If students need to enhance their knowledge of greenhouse gases and their impact on climate, they can visit this link to NASA resource about the causes of climate change.	**5 min**
3. ENGAGE Discuss how temperatures on Earth would be different if we were to increase or decrease the amount of greenhouse gases in the atmosphere. Have the students work with a partner to engage in a Think-Pair-Share about the discussion topic provided above. Introduce how climate models can account for changing greenhouse gas concentrations through Representative Concentration Pathways (RCPs). ***Assessment Opportunity #2 (Student discussions about the impact of changing greenhouse gas concentrations)***	The students work with a partner through a Think-Pair-Share to discuss how temperatures on Earth would be different if we were to increase or decrease the amount of greenhouse gases in the atmosphere. The students learn how climate models can account for changing greenhouse gas concentrations through Representative Concentration Pathways (RCPs).	**10 min**

<table>
<tr><th>What the teacher does</th><th>What the student does</th><th>Time</th></tr>
<tr><td>4. EXPLORE Introduce the students to the Graphic Organizer for the Representative Concentration Pathways (RCPs) based on the paper from Nazarenko et al., 2015 titled Future Climate Change Under RCP Emission Scenarios with GISS ModelE2.

Circulate the room as the students complete the graphic organizer. Pay special attention to student interpretation of the RCP scenarios in terms of their respective radiative forcings.

Assessment Opportunity #3 (Student answers to questions in the graphic organizer)</td><td>The students read the activity description and directions to the Graphic Organizer for the Representative Concentration Pathways (RCP) scenarios.

The students begin completing the graphic organizer.

Once the students finish the graphic organizer, they will work with a partner to go over the answers. Students will make adjustments to their organizers based on partner discussions.</td><td>1.5 periods</td></tr>
<tr><td>5. EXPLAIN Introduce the students to the Evaluating Simulations from the RCP Scenarios activity.

Circulate the room to ensure the students are properly distinguishing between the simulations available in Figure 1 and Figure 2. Ensure the students understand the meaning of positive/negative values in Figure 2.
Bring the class together for a discussion if many students are confusing positive values in Figure 2 with warm temperatures and negative values with cold temperatures. Positive values indicate that the RCP 4.5, 6.0, or 8.5 scenario has a greater temperature than the RCP 2.6 scenario.
Discuss student answers to Q9 of the activity. Use this time to ensure all students understand why scientists use difference maps to accurately compare two different sets of simulations

Assessment Opportunity #4 (Student answers to questions from the Evaluating Simulations from the RCP Scenarios activity)</td><td>The students begin the Evaluating Simulations from the RCP Scenarios activity.

The students directly compare temperature projections from the four RCP scenarios by analyzing Figure 1 and Figure 2. The students learn through analysis questions that the difference maps for the RCP scenarios presented in Figure 2 allow for an easier and more effective output comparison.

The students discuss their answers to Q9 of the activity.</td><td>1 period</td></tr>
<tr><td>6. ELABORATE & EVALUATE Introduce the students to the prompt for the whole-class discussion by providing students the Class Discussion worksheet. The prompt is Which RCP scenario do you think will be our reality by the year 2100?</td><td>The students learn about the prompt for the student-led whole-class discussion.

The students contribute to the creation of class discussion norms.</td><td>1 period</td></tr>
</table>

What the teacher does	What the student does	Time
Work together as a class to create discussion norms. Example norms have been provided on the Class Discussion worksheet. Provide students with the discussion rubric that will be used to assess the students. Give the students 20 minutes to prepare for the discussion. Circulate as the students are gathering resources from the internet to ensure students are using their preparation time effectively. Begin the student-led class discussion. Try to minimize the teacher role in the discussion and only interject when need-be. The discussion should take 20 minutes. Use the last 10 minutes of class time to debrief on the discussion. The debrief could be based on common themes or challenges from the discussion. ***Assessment Opportunity #5 (Student statements during the class discussion based on the discussion rubric)***	The students review the guidelines of the discussion rubric. The students use 20 minutes of class time to prepare for the discussion by referencing past class topics and searching for resources on the internet. The students use their resources to lead a whole-class discussion based on the prompt ***Which RCP scenario do you think will be our reality by the year 2100?*** The students engage in a debrief about the discussion based on common themes or challenges.	**20 min prep** **20 min discussion** **10 min debrief**
7. Administer the Daily Formative Assessment (DFA) to the students. ***Assessment Opportunity #6 (Student answers to the DFA)***	The students individually answer questions for the Daily Formative Assessment. The students will submit their answers at the end of class.	**10 min**

Summary/Conclusion: The students individually answer questions for the Daily Formative Assessment. The students will submit their answers at the end of class.

Higher Order Questions:

1. Evaluate how easy or difficult it was for you to answer questions Q1 through Q3 based on Figure

2. Why is it difficult to accurately determine differences in temperature between the RCP scenarios based on the maps provided in Figure 1?

3. Was Figure 1 or Figure 2 was more useful in answering questions Q1 to Q3 (same as Q6 to Q8)? Why?

Differentiated Instruction:

- The students are exposed to content in written, oral, and visual forms (multiple modalities exist).

- Students can use colored pencils to draw diagrams and annotate notes in a way that is meaningful to them. Students will also have access to highlighters during reading activities.

- Students are asked both higher and lower level questions so all students can answer questions at their particular academic level.

- Students are provided with a graphic organizer to help them learn the main ideas of the research paper. The graphic organizer also includes additional information not presented in the article to help enhance student understanding.

- Students are given time to answer questions during think pair share/group activities.

- Students who need extra support can join the teacher for small group instruction and more efficient feedback.

- Students who are performing at a higher level can complete the tasks provided in the For Further Exploration part of the lesson plan.

- Students with a visual impairment can receive additional guidance from a sighted teacher about the color schemes in temperature-based maps. At the end of the activity titled Evaluating Model Output from the RCP Scenarios, additional descriptions about the colors in Figure 1 and Figure 2 are provided for teachers to provide students in need.

Daily Formative Assessment:

1. During the month of January, how do the differences in temperature projections between the RCP 4.5 and 2.6 scenario change overtime?

2. During the month of July, how do the differences in temperature projections between the RCP 4.5 and 2.6 scenario change overtime?

Next Lesson: The next lesson the students will download temperature projection simulations from the GISS ModelE2 for the RCP 2.6, 4.5 and 8.5 scenarios for further analysis in RStudio. The students will learn how to write code using the R language to create line plots to evaluate monthly average differences in temperature out to the year 2100 for the RCP 4.5 – RCP 2.6 and RCP 8.5 – RCP 2.6 scenarios.

For Further Exploration:

1. Go to this link about forcings in the GISS ModelE2 to read more about the forcings in the GISS ModelE2 climate model.
2. Go to this link to a research article about climate mitigation strategies by Wynes & Nicholas (2017) and specifically look at Figure 1 to determine the best strategies for reducing carbon dioxide emissions. Students can also have the freedom to read the paper about lifestyle choices and their impact on emissions.

3. Go to this link to the Intergovernmental Panel on Climate Change (IPCC) Summary for Policy Makers and specifically analyze Figure SPM.5 on page #14. This will allow students to obtain more information about the influence of different greenhouse gases on radiative forcings.
4. Go to this link to the NASA climate website to learn more about the evidence for climate change, the effects of climate change, and potential solutions.

Notes For Revision:

D. Supporting Documents (order according to sequence of lesson)

Name: ____ **Date:** ________________

Graphic Organizer – Representative Concentration Pathways (RCPs)
Future Climate Change Under RCP Emission Scenarios with GISS ModelE2

Activity Description: In this activity the students will read Section 3 of a paper by Nazarenko et al., 2015 titled *Future Climate Change Under RCP Emission Scenarios with GISS ModelE2* to learn about the different Representative Concentration Pathways (RCP) scenarios that future climate change projections from the NASA GISS ModelE2 are based on. The students will complete the graphic organizer below to learn about the main ideas behind the RCP scenarios. Link to Nazarenko et al., 2015 paper

Directions: Begin completing the graphic organizer by working on the Background Information section. Then, click on the link above to access the **Nazarenko et al., 2015** paper and find Section 3 titled Representative Concentration Pathways (RCP) Experiments. As you read only Section 3, answer the questions in the second section of the graphic organizer titled *Section 3* ***Narenko et al. 2015*** *Representative Concentration Pathways (RCP) Experiments.* Some sections of the graphic organizer may contain additional information to help students develop a deeper understanding of the RCP scenarios.

Questions/Information	Answers
Background Information (Not Included in Nazarenko et al., 2015) Representative Concentration Pathways (RCP) were designed to give global climate models different scenarios based on different amounts of greenhouse gas emissions and their associated total radiative forcings. RCP scenarios can also be based on land use projections and projections on the amount and type of aerosols in the atmosphere. **Q1.** Why do you think it is important for global climate models that make future climate projections to have different model scenarios based on the amounts of greenhouse gases?	**A1.**
Radiative forcings are defined as the difference between incoming solar radiation (insolation) absorbed by the Earth and energy sent back towards space. Greenhouse gases and other variables such as surface material and atmospheric aerosols can influence the difference between this incoming and	**A2.**

Questions/Information	Answers
outgoing energy. A positive radiative forcing means the Earth is receiving more energy than it is radiating back towards space, leading to warming. **Q2.** Based on the information provided above, explain what a negative radiative forcing means.	
Based on knowledge from previous units, increasing greenhouse gases lead to warming on Earth as outgoing longwave radiation (infrared energy) is absorbed by the greenhouse gases. **Q3.** Based on the information provided above, predict whether increasing greenhouse gases in Earth's atmosphere would lead to a positive or negative radiative forcing. Then, justify your answer.	**A3.** **Justification:**
Based on section 3 Narenko et al. 2015 Representative Concentration Pathways (RCP) Experiments from this point on. **Q4**. How many RCP scenarios are there and what is the name of each scenario?	**A4.**
The four RCP scenarios are based on net greenhouse gas radiative forcing values in the year 2100. **Q5**. What is the dominant factor that influences the net greenhouse gas radiative forcings in the year 2100?	**A5.**
The four RCP Scenarios get their names from the amount of their net greenhouse gas radiative forcing by the year 2100. For example, RCP 2.6 means a scenario where the net greenhouse gas radiative forcing is 2.6 W/m^2 by the year 2100. **Q6**. Based on the information provided above, what is the net greenhouse gas radiative forcing associated with each RCP scenario provided?	**A6.** **RCP 4.5:** **RCP 6.0:** **RCP 8.5:**

Questions/Information	Answers
The simulations students will be working with in this unit are future projections from the GISS ModelE2 from all RCP scenarios out to the year 2100.	**A7.**
Figure #2 shows greenhouse gas projections for CO_2 (carbon dioxide), CH_4 (methane), N_2O (nitrous oxide), and CFCs (chlorofluorocarbons) out to the year 2500.	**A8.**
Analyze Figure 2, including the caption, and then answer the questions that follow.	**A9.**
Q7. For all greenhouse gases, describe the trend in concentration totals from 1850 to present-day.	
Q8. For only CO_2, describe the trend in concentrations over time under the RCP 2.6 scenario.	**A10.**
Q9. For only CO_2, describe the trend in concentrations over time under the RCP 4.5 scenario.	**A11.**
Q10. For only CO_2, describe the trend in concentrations over time under the RCP 6.0 scenario.	**A12.**
Q11. For only CO_2, describe the trend in concentrations over time under the RCP 8.5 scenario.	**Justification:**
Q12. Based on the information provided in Figure 2, which RCP scenario predicts the greatest increase in temperatures on Earth? Justify your answer in terms of greenhouse gases and outgoing longwave radiation.	**A13.**
Q13. Based on the information provided in Figure 2, which RCP scenario predicts the smallest increase in temperatures on Earth? Justify your answer in terms of greenhouse gases and outgoing longwave radiation.	**Justification:**

Name: ____ **Date:** _______________

Evaluating Model Output from the RCP Scenarios

Activity Description: In this activity, the students will learn how to effectively compare model output from the RCP scenarios. Specifically, the students will learn the importance of evaluating difference maps that compare the RCP 4.5, RCP 6.0, and RCP 8.5 scenarios to the RCP 2.6 scenario. The RCP 2.6 scenario is the best-case scenario, and it is important to compare the outcomes of the other scenarios to the best-case scenario to make prompt and effective decisions regarding climate change.

The students will first compare RCP scenarios by analyzing Figure 1, which shows a separate map of temperature projections for each scenario. Students will be asked to answer Q1 to Q3 based on Figure 1 and then will be asked questions about the difficulty of the analysis. Then, the students will be asked to answer the same questions from Q1 to Q3 (the questions are now Q6 to Q8) based on Figure 2, which shows the difference maps. Students will then be able to evaluate whether Figure 1 or Figure 2 is more useful for comparing simulations between RCP scenarios.

Simulated Temperature Projection Maps of Each RCP Scenario

Answer questions Q1 to Q5 based on Figure 1 below. Figure 1 shows the global near surface temperature projection for each RCP scenario during December 2100. Figure 1 has been broken up into 1a, 1b, 1c, and 1d to represent RCP 2.6, 4.5, 6.0, and 8.5, respectively.

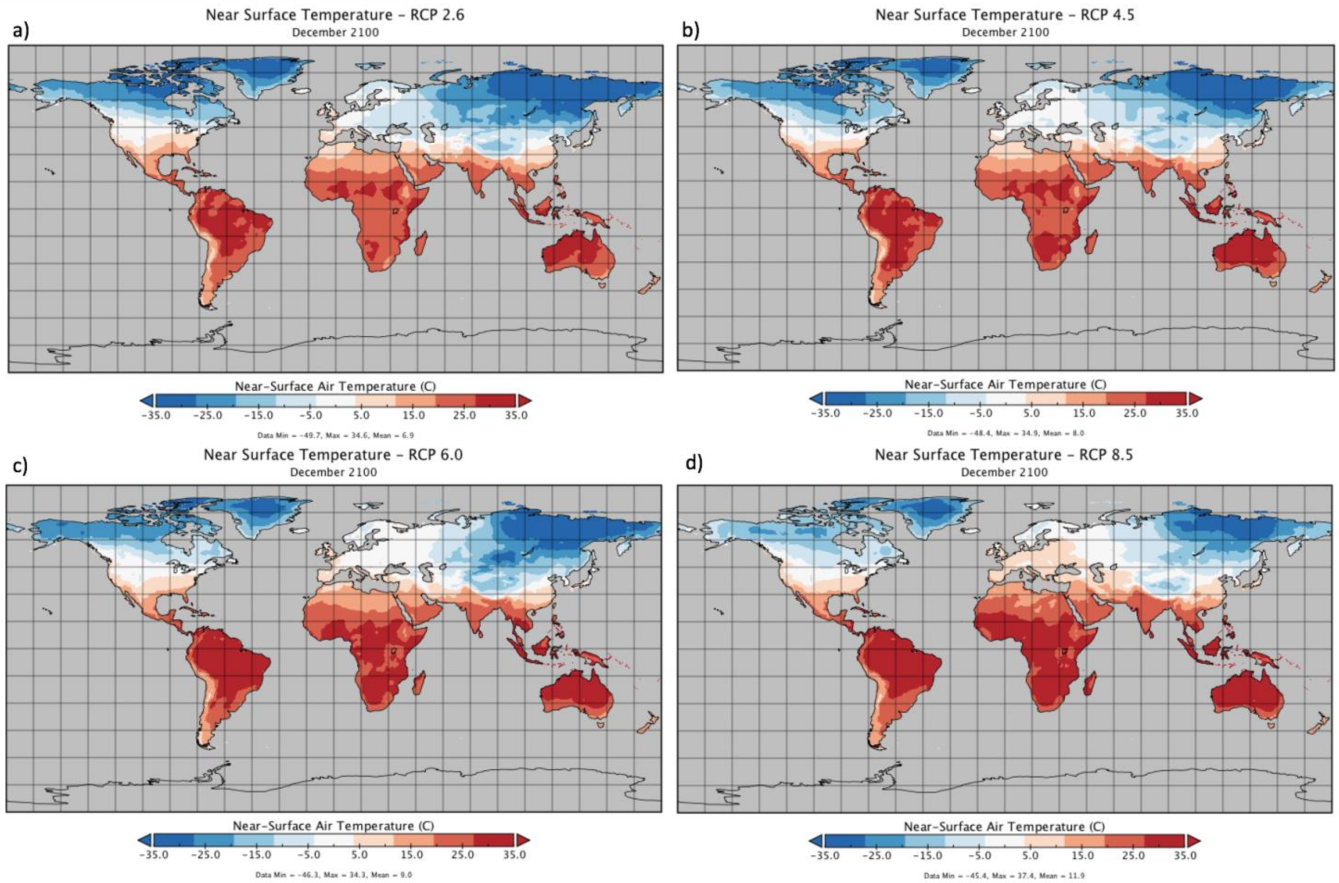


Figure 1 – Near surface temperature during December 2100 for each RCP projection scenario a) RCP 2.6 b) RCP 4.5 c) RCP 6.0 d) RCP 8.5. Red colors indicate locations with higher surface air temperatures while blue colors indicate locations with colder surface air temperatures.

Q1. Based on Figure 1 above, which RCP scenario (RCP 4.5, 6.0, or 8.5) leads to greater temperatures in South America by December 2100 when compared to the RCP 2.6 scenario?

____

Q2. Based on Figure 1 above, which RCP scenario (RCP 4.5, 6.0, or 8.5) leads to greater temperatures in Africa by December 2100 when compared to the RCP 2.6 scenario?

____

Q3. Based on Figure 1 above, which RCP scenario (RCP 4.5, 6.0, or 8.5) leads to lower temperatures in the United States by December 2100 when compared to the RCP 2.6 scenario?

____

Q4. Evaluate how easy or difficult it was for you to answer questions Q1 through Q3 based on Figure 1.

____

Q5. Why is it difficult to accurately determine differences in temperature between the RCP scenarios based on the maps provided in Figure 1?

____

____

Simulated Temperature Projection Difference Maps – RCP 4.5, 6.0, and 8.5 compared to RCP 2.6

Answer questions Q6 to Q9 based on Figure 2 below. Figure 2 shows difference maps (temperature anomaly maps) of global near surface temperature during December 2100 for RCP 4.5 – RCP 2.6, RCP 6.0 – RCP 2.6, and RCP 8.5 – RCP 2.6. Figure 2 has been broken up into 2a, 2b, 2c to represent RCP 4.5 – RCP 2.6, RCP 6.0 – RCP 2.6, and RCP 8.5 – RCP 2.6, respectively.

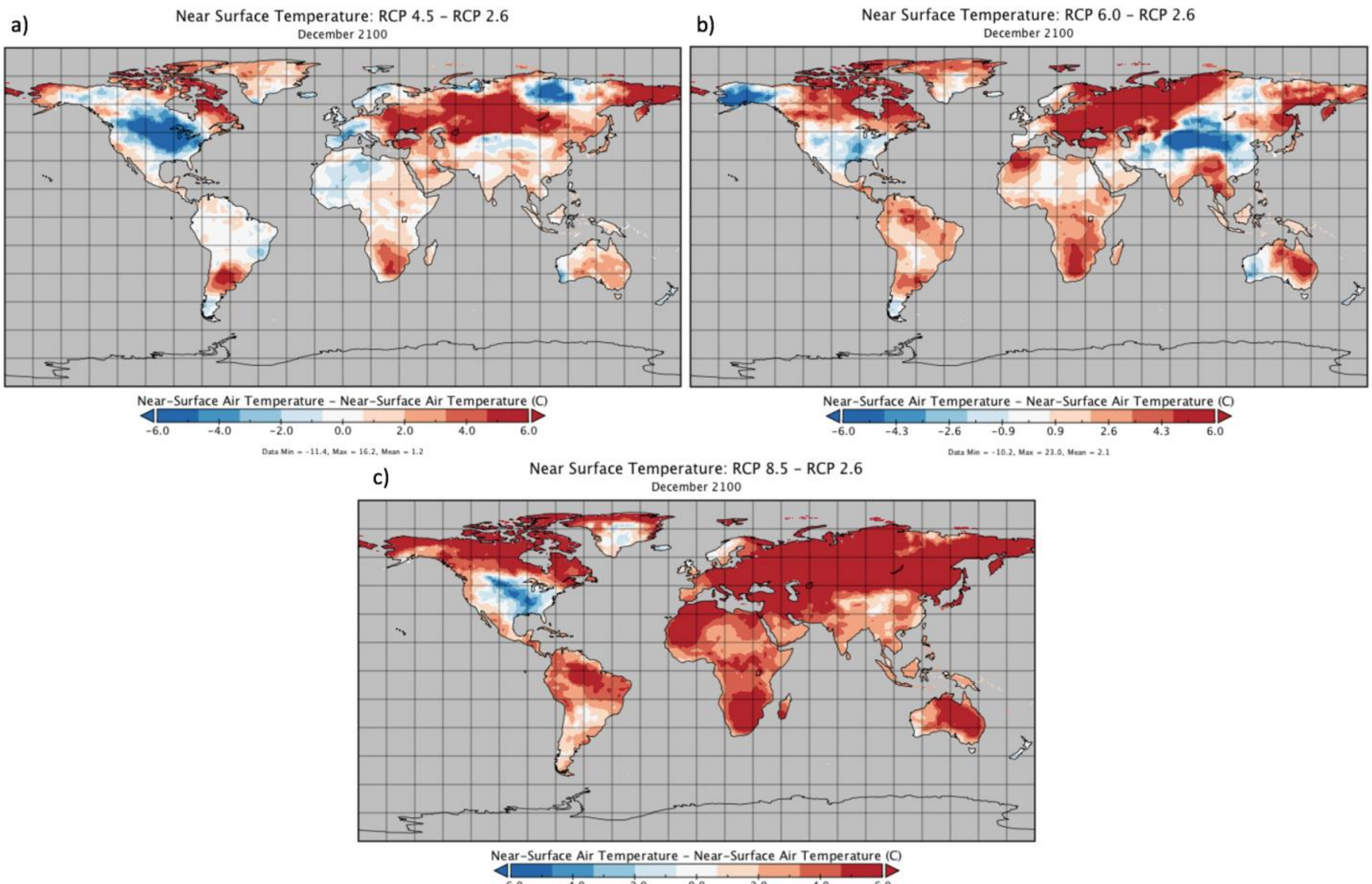


Figure 2 – Near surface temperature difference maps during December 2100 for a) RCP 4.5 – RCP 2.6 b) RCP 6.0 – RCP 2.6 c) RCP 8.5 – RCP 2.6. Red colors indicate locations where the RCP 2.6 scenario has lower temperatures, while blue colors indicate locations where the RCP 2.6 scenario has higher temperatures.

The maps in Figure 2 above are difference maps used to directly compare the RCP 4.5, RCP 6.0, and RCP 8.5 scenarios to the best-case scenario of RCP 2.6. In each map, the simulations from the RCP 2.6 scenario is subtracted from the other scenarios. For example, in Figure 2a the map was created by subtracting RCP 2.6 from RCP 4.5 (RCP 4.5 – RCP 2.6). All positive values in the map indicate the locations where the RCP 4.5 temperature is projected to be greater than then RCP 2.6 temperature. On the other hand, all negative values indicate locations where the RCP 4.5 temperature is projected to be less than then RCP 2.6 temperature. The same convention is used for Figure 2b and Figure 2c. Please note that all maps have the same scale.

Q6 (Same as Q1). Based on Figure 2 above, which RCP scenario (RCP 4.5, 6.0, or 8.5) leads to greater temperatures in South America by December 2100 when compared to the RCP 2.6 scenario?

____

Q7 (Same as Q2). Based on Figure 2 above, which RCP scenario (RCP 4.5, 6.0, or 8.5) leads to greater temperatures in Africa by December 2100 when compared to the RCP 2.6 scenario?

____

Q8 (Same as Q3). Based on Figure 2 above, which RCP scenario (RCP 4.5, 6.0, or 8.5) leads to lower temperatures in the United States by December 2100 when compared to the RCP 2.6 scenario?

____

Q9. Was Figure 1 or Figure 2 more useful in answering questions Q1 to Q3 (same as Q6 to Q8)? Why?

____

____

Additional Figure Descriptions for Students

This worksheet provides additional information about the Figures that could be provided to students who have a visual impairment. This will allow students to effectively answer the questions to the Evaluating Model Output from the RCP Scenarios activity these Figures are based on.

Figure 1: Figure 1a, b, c, d show near surface temperature values during December 2100 for all RCP scenarios. Red colors indicate locations with higher temperatures while blue colors indicate locations with lower temperatures. All of South America, Africa, and Australia show red, which indicates higher temperatures in all scenarios. The southern half of the United States, southern Middle East, and southernmost Asia also show red, indicating higher temperatures for all scenarios. Northernmost North America and Asia show blue, which indicates colder temperatures for all scenarios. The greatest difference in colder temperatures occurs in western Europe for the RCP 8.5 scenario. In all other scenarios, Europe shows cold temperatures, except for the RCP 8.5 scenarios when temperature is warm.

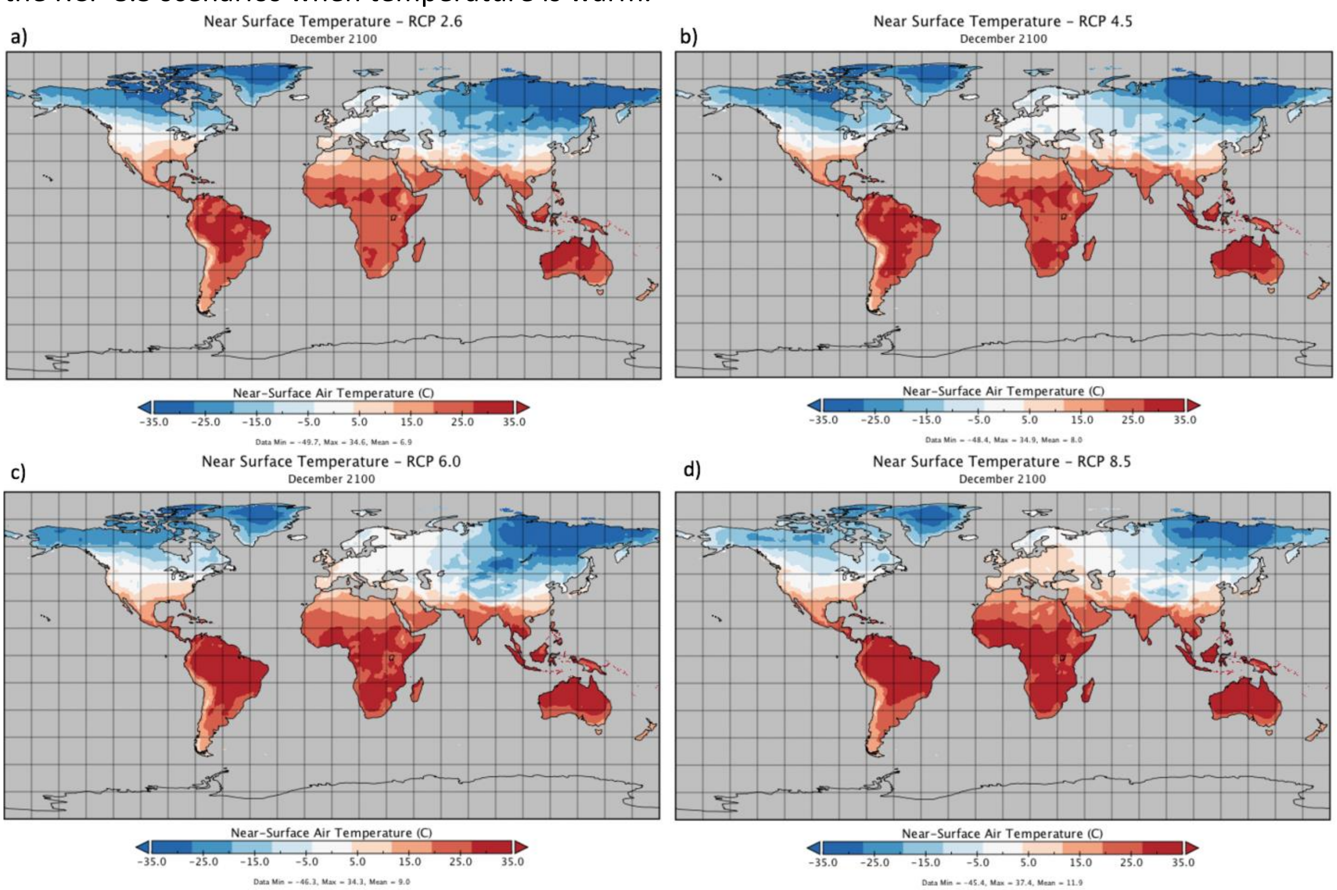
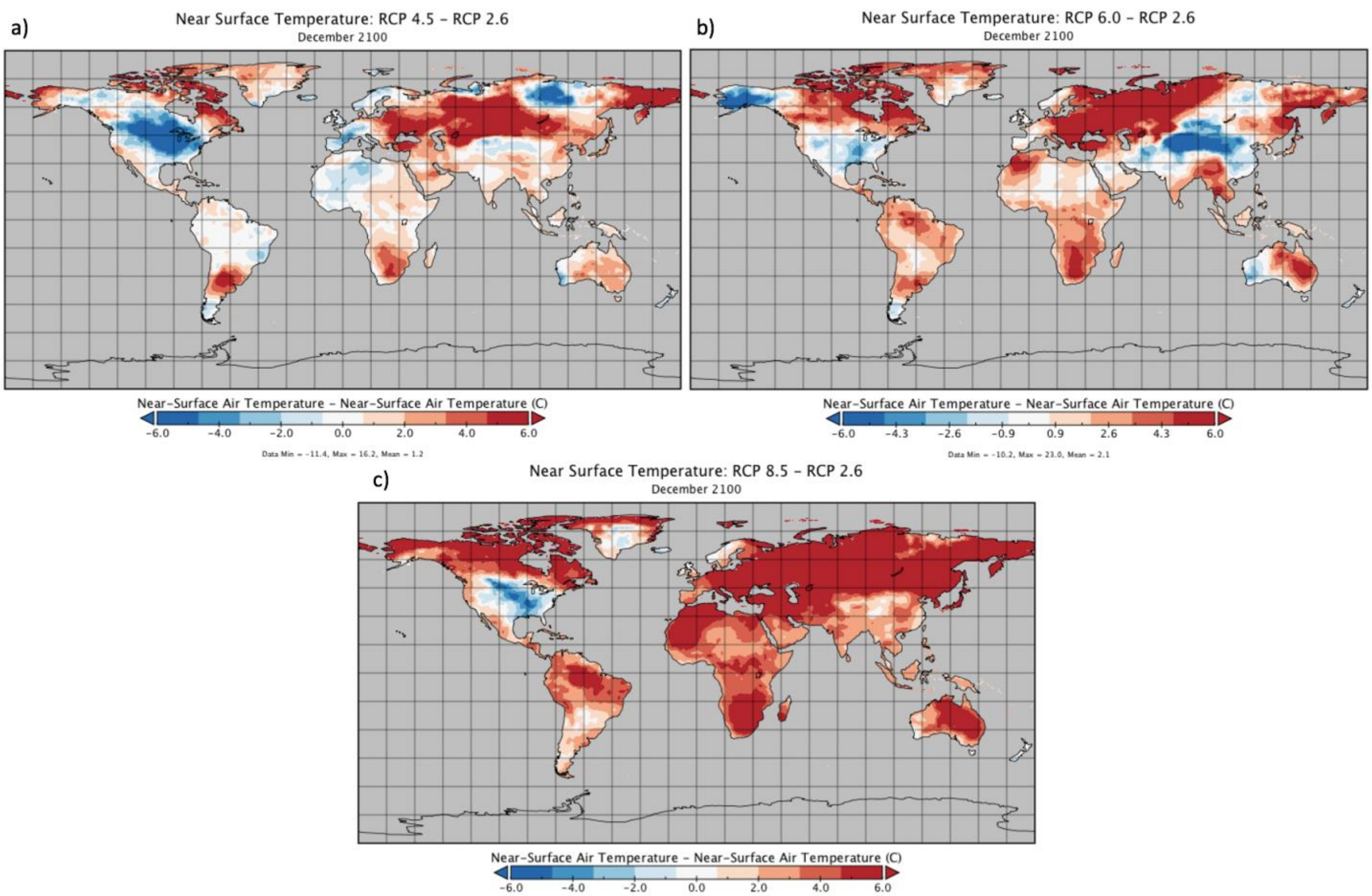


Figure 2: Figure 2a, b, c shows the difference in temperature between the RCP 4.5, RCP 6.0, and RCP 8.5 scenarios compared to the baseline scenario of RCP 2.6. Red colors indicate locations where the temperature of the respective RCP scenario is higher than the RCP 2.6 scenario. On the other hand, blue colors indicate locations where the temperature of the respective RCP scenario is lower than the RCP 2.6 scenario. According to the Figure, the RCP 8.5 scenario results in much higher temperatures than the RCP 2.6 scenario, particularly

in northernmost North America, South America, Africa, Australia, Europe, and Asia. The RCP 2.6 scenario has higher temperatures compared to the RCP 4.5 scenario in the United States.



Name: ____ **Date:** _______________

Class Discussion:
Which RCP scenario will be our reality by 2100?

Activity Description: In this activity, the students will engage in a whole-class discussion based on the following prompt:

Which RCP scenario do you think will be our reality by the year 2100?

Students should be given 20 minutes to prepare their discussion by reviewing the rubric, conducting research on the internet, and using class notes. Then, 20 minutes should be designated for the students to lead the discussion. One of the goals for the discussion is for the teacher to interject as little as possible. After the discussion, 10 minutes should be devoted to a debrief facilitated by the teacher.

Discussion Norms: It is recommended for the class to work together to develop norms for the discussion. A few examples of discussion norms are provided below.

- One mic – there should be one speaker at a time
- If you are not speaking, you should be actively listening
- Use respectful language at all times
- If you disagree, disagree with the statement and not the person

Discussion Rubric: The rubric below is designed to provide students with high-quality expectations throughout the discussion. Link to the website the rubric was adapted from

Criteria	Exceeds Expectations	Meets Expectations	Approaching Expectations	Unsatisfactory
Knowledge of Content	☐ Consistently and accurately utilized related academic vocabulary ☐ Consistently and accurately referenced material from past topics to make claims/expand on ideas	☐ Accurately incorporates related academic vocabulary ☐ Accurately references material from past topics to make claims/expand on ideas	☐ Uses academic vocabulary, but with one or more errors. ☐ Attempts to reference material from past topics, but references could be more accurate	☐ Does not use academic vocabulary ☐ Does not reference material from past topics
Engagement	☐ Consistently contributes to discussion by offering quality ideas and asking appropriate questions ☐ Actively engages others in class discussions by inviting their comments ☐ Effectively identifies and summarizes main points	☐ Contributes to discussion by offering ideas and asking questions ☐ Often engages others in class discussions by inviting their comments ☐ Identifies and summarizes main points	☐ Occasionally contributes to discussion by offering ideas and asking questions ☐ Sometimes engages others in class discussions ☐ Sometimes has an understanding of main points	☐ Fails to contribute to discussion ☐ Fails to invite comment/opinions from other students ☐ Demonstrates little understanding of main points
Preparedness	☐ Abundant resources were prepared and utilized throughout the discussion	☐ An adequate amount of resources was prepared and utilized throughout the discussion	☐ Few resources were prepared and utilized throughout the discussion	☐ No resources were prepared or utilized throughout the discussion
Professionalism	☐ Consistently positive with a cooperative attitude during the discussion ☐ Always supportive of other students' ideas	☐ Usually positive and cooperative during the discussion ☐ Often supportive of other students' ideas	☐ Seldom actively participates in the discussion ☐ Sometimes supportive of other students' ideas	☐ Rarely participates in the discussion ☐ Occasional disruptive behavior

Name: Answers

Answers: Graphic Organizer – Representative Concentration Pathways (RCPs)
Future Climate Change Under RCP Emission Scenarios with GISS ModelE2

Activity Description: In this activity the students will read Section 3 of a paper by Nazarenko et al., 2015 titled *Future Climate Change Under RCP Emission Scenarios with GISS ModelE2* to learn about the different Representative Concentration Pathways (RCP) scenarios that future climate change projections from the NASA GISS ModelE2 are based on. The students will complete the graphic organizer below to learn about the main ideas behind the RCP scenarios. Link to Nazarenko et al., 2015 paper

Directions: Begin completing the graphic organizer by working on the Background Information section. Then, click on the link above to access the **Nazarenko et al., 2015** paper and find Section 3 titled Representative Concentration Pathways (RCP) Experiments. As you read only Section 3, answer the questions in the second section of the graphic organizer titled *Section 3* ***Narenko et al. 2015*** *Representative Concentration Pathways (RCP) Experiments.* Some sections of the graphic organizer may contain additional information to help students develop a deeper understanding of the RCP scenarios.

Question/Information	Answers
Background Information (Not Included in Nazarenko et al., 2015) Representative Concentration Pathways (RCP) were designed to give global climate models different scenarios based on different amounts of greenhouse gas emissions and their associated total radiative forcings. RCP scenarios can also be based on land use projections and projections on the amount and type of aerosols in the atmosphere. **Q1.** Why do you think it is important for global climate models that make future climate projections to have different scenarios based on the amounts of greenhouse gases?	**A1. It is difficult for scientists to accurately predict how greenhouse gas concentrations will change in the future and therefore the different pathways provide information on future climate projections based on a variety of greenhouse gas concentration scenarios.**
Radiative forcings are defined as the difference between incoming solar radiation (insolation) absorbed by the Earth and energy sent back towards space. Greenhouse gases and other parameters can influence the difference between this incoming and outgoing energy. A positive radiative forcing means the Earth is receiving more energy than it is radiating back towards space, leading to warming.	**A2. A negative radiative forcing means that Earth is radiating more energy back towards space than it is receiving, leading to cooling.**

Question/Information	Answers
Q2. Based on the information provided above, explain what a negative radiative forcing means.	
Based on knowledge from previous units, increasing greenhouse gases lead to warming on Earth as outgoing longwave radiation (infrared energy) is absorbed by the greenhouse gases. **Q3.** Based on the information provided above, predict whether increasing greenhouse gases in Earth's atmosphere would lead to a positive or negative radiative forcing. Then, justify your answer.	**A3. Increasing greenhouse gases would lead to positive radiative forcing.** **Justification: Increasing greenhouse gases would lead to more outgoing longwave radiation (infrared energy) getting trapped in Earth's atmosphere. Therefore, less energy would be radiating back towards space, resulting in more incoming energy compared to outgoing.**
Based on section 3 Narenko et al. 2015 Representative Concentration Pathways (RCP) Experiments from this point on **Q4**. How many RCP scenarios are there and what is the name of each scenario?	**A4. There are four RCP scenarios; RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5.**
The four RCP scenarios are based on net greenhouse gas radiative forcing values in the year 2100. **Q5**. What is the dominant factor that influences the net greenhouse gas radiative forcings in the year 2100?	**A5. The dominant factor that influences the net greenhouse gas radiative forcings is carbon dioxide (CO_2).**
The four RCP Scenarios get their names from the amount of their net greenhouse gas radiative forcing by the year 2100. For example, RCP 2.6 means a scenario where the net greenhouse gas radiative forcing is 2.6 W/m^2 by the year 2100. **Q6**. Based on the information provided above, what is the net greenhouse gas radiative forcing associated with each RCP scenario provided?	**A6.** **RCP 4.5: 4.5 W/m^2** **RCP 6.0: 6.0 W/m^2** **RCP 8.5: 8.5 W/m^2**
The simulations students will be working with in this unit are future projections from the GISS ModelE2 from all RCP scenarios out to the year 2100. Figure #2 shows greenhouse gas projections for CO_2 (carbon dioxide), CH_4 (methane), N_2O (nitrous oxide), and CFCs (chlorofluorocarbons) out to the year 2500.	**A7. All greenhouse gases show an increase in concentrations from the year 1850 to present-day.** **A8. For RCP 2.6, carbon dioxide increases from the year 1850 until about the year 2050 to a total of about 450 ppm, and then steadily decreases to the year 2500.**

Question/Information	Answers
Analyze Figure 2, including the caption, and then answer the questions that follow. **Q7**. For all greenhouse gases, describe the trend in concentration totals from 1850 to present-day. **Q8**. For only CO_2, describe the trend in concentrations over time under the RCP 2.6 scenario. **Q9**. For only CO_2, describe the trend in concentrations over time under the RCP 4.5 scenario. **Q10**. For only CO_2, describe the trend in concentrations over time under the RCP 6.0 scenario. **Q11**. For only CO_2, describe the trend in concentrations over time under the RCP 8.5 scenario. **Q12**. Based on the information provided in Figure 2, which RCP scenario predicts the greatest increase in temperatures on Earth? Justify your answer in terms of greenhouse gases and outgoing longwave radiation. **Q13**. Based on the information provided in Figure 2, which RCP scenario predicts the smallest increase in temperatures on Earth? Justify your answer in terms of greenhouse gases and outgoing longwave radiation.	**A9. For RCP 4.5, carbon dioxide increases from the year 1850 until about the year 2075 to a total of about 530 ppm, and then remains relatively steady to the year 2500.** **A10. For RCP 6.0, carbon dioxide increases from the year 1850 until about the year 2125 to a total of about 750 ppm, and then remains relatively steady to the year 2500.** **A11. For RCP 8.5, carbon dioxide increases from the year 1850 until about the year 2250 to a total of about 1960 ppm, and then remains relatively steady to the year 2500.** **A12. RCP 8.5 will lead to the greatest increases in temperatures on Earth.** **Justification: Since RCP 8.5 will lead to the greatest increases in CO_2 concentrations, more outgoing longwave energy will be trapped in Earth's atmosphere. This in turn leads to a positive radiative forcing, increasing temperatures in Earth.** **A13. RCP 2.6 will lead to the smallest increases in temperatures on Earth.** **Justification: Since RCP 2.6 will lead to the smallest increases in CO_2 concentrations, less outgoing longwave energy will be trapped compared to other scenarios. This leads to a lower positive radiative forcing and smaller increases in temperature.**

National Aeronautics and Space Administration
Goddard Institute for Space Studies
New York, N.Y.

Name: Answers **Date:** _______________

Answers: Evaluating Model Output from the RCP Scenarios

Activity Description: In this activity, the students will learn how to effectively compare output from the RCP scenarios. Specifically, the students will learn the importance of evaluating difference maps that compare the RCP 4.5, RCP 6.0, and RCP 8.5 scenarios to the RCP 2.6 scenario. The RCP 2.6 scenario is the best-case scenario, and it is important to compare the outcomes of the other scenarios to the best-case scenario to make prompt and effective decisions regarding climate change.

The students will first compare RCP scenarios by analyzing Figure 1, which shows a separate map of temperature projections for each scenario. Students will be asked to answer Q1 to Q3 based on Figure 1 and then will be asked questions about the difficulty of the analysis. Then, the students will be asked to answer the same questions from Q1 to Q3 in Q6 to Q8 based on Figure 2, which shows the difference maps. Students will then be able to evaluate whether Figure 1 or Figure 2 is more useful for comparing simulations between RCP scenarios.

Simulated Temperature Projection Maps of Each RCP Scenario

Answer questions Q1 to Q5 based on Figure 1 below. Figure 1 shows the global near surface temperature projection for each RCP scenario during December 2100. Figure 1 has been broken up into 1a, 1b, 1c, and 1d to represent RCP 2.6, 4.5, 6.0, and 8.5, respectively. Please note that all maps have the same scale.

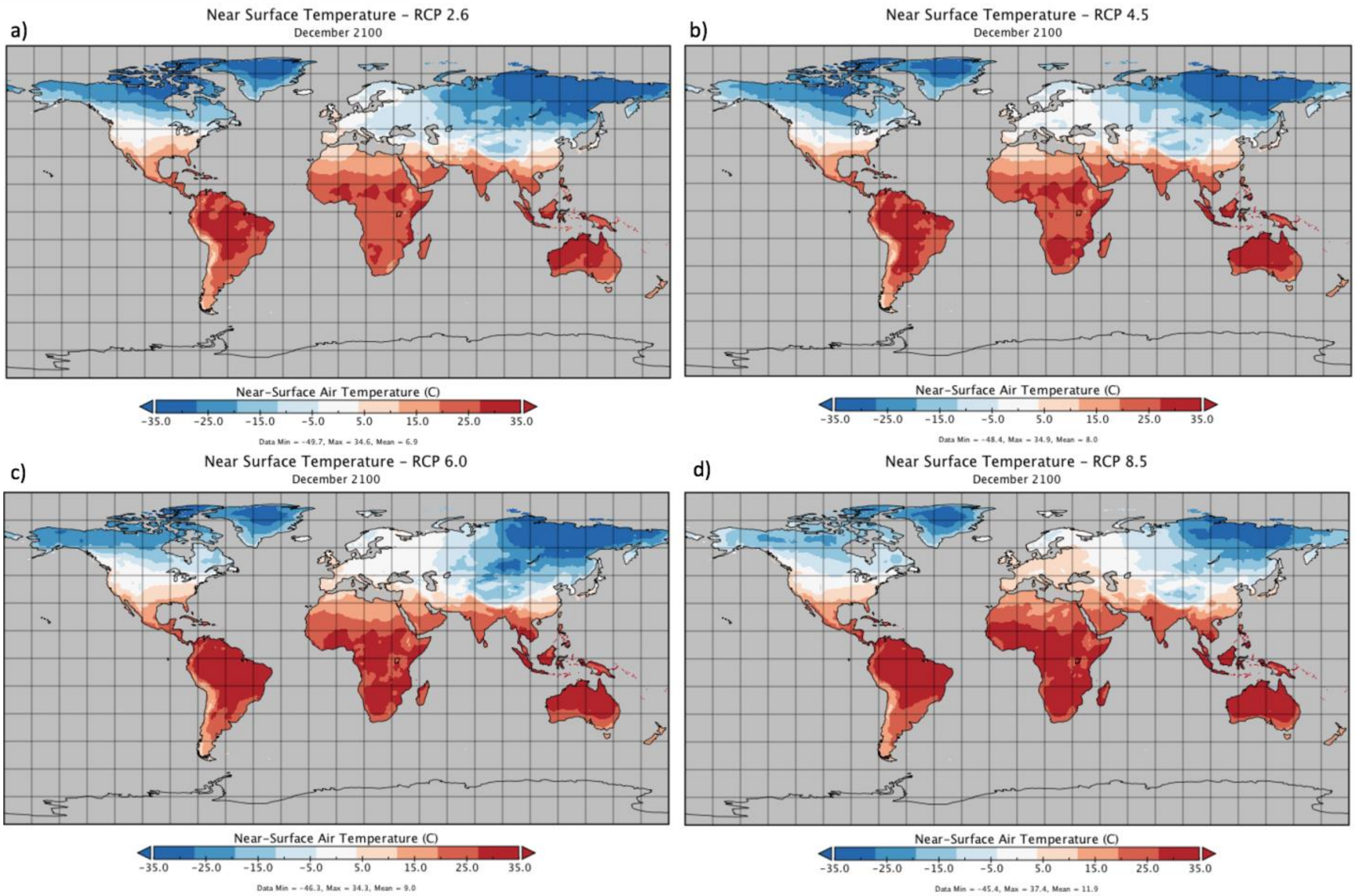


Figure 2 – Near surface temperature during December 2100 for each RCP projection scenario a) RCP 2.6 b) RCP 4.5 c) RCP 6.0 d) RCP 8.5. Red colors indicate locations with higher surface air temperatures while blue colors indicate locations with colder surface air temperatures.

Q1. Based on Figure 1 above, which RCP scenario (RCP 4.5, 6.0, or 8.5) leads to greater temperatures in South America by December 2100 when compared to the RCP 2.6 scenario?

Should be the RCP 8.5 scenario, but students should not be able to determine this by looking at Figure 1. Expect the students to have a difficult time answering this.

Q2. Based on Figure 1 above, which RCP scenario (RCP 4.5, 6.0, or 8.5) leads to greater temperatures in Africa by December 2100 when compared to the RCP 2.6 scenario?

Should be the RCP 8.5 scenario, but students should not be able to determine this by looking at Figure 1. Expect the students to have a difficult time answering this.

Q3. Based on Figure 1 above, which RCP scenario (RCP 4.5, 6.0, or 8.5) leads to lower temperatures in the United States by December 2100 when compared to the RCP 2.6 scenario?

Should be the RCP 4.5 scenario, but students should not be able to determine this by looking at Figure 1. Expect the students to have a difficult time answering this.

Q4. Evaluate how easy or difficult it was for you to answer questions Q1 through Q3 based on Figure 1.

Students should be answering that it was difficult to answer questions Q1 to Q3 based on Figure 1.

Q5. Why is it difficult to accurately determine differences in temperature between the RCP scenarios based on the maps provided in Figure 1?

Significant changes in temperature between RCP scenarios can be small in value and hard to discern from one map to the next. For example, a 2-degree change in temperature is significant, but a two-degree difference may not lead to a change in color on two different maps. Therefore, at a glance, it is difficult to determine which RCP scenario results in greater or less temperatures when compared to the RCP 2.6 scenario.

Simulated Temperature Projection Difference Maps – RCP 4.5, 6.0, and 8.5 compared to RCP 2.6

Answer questions Q6 to Q10 based on Figure 2 below. Figure 2 shows difference maps (temperature anomaly maps) of global near surface temperature during December 2100 for RCP 4.5 – RCP 2.6, RCP 6.0 – RCP 2.6, and RCP 8.5 – RCP 2.6. Figure 2 has been broken up into 2a, 2b, 2c to represent RCP 4.5 – RCP 2.6, RCP 6.0 – RCP 2.6, and RCP 8.5 – RCP 2.6, respectively.

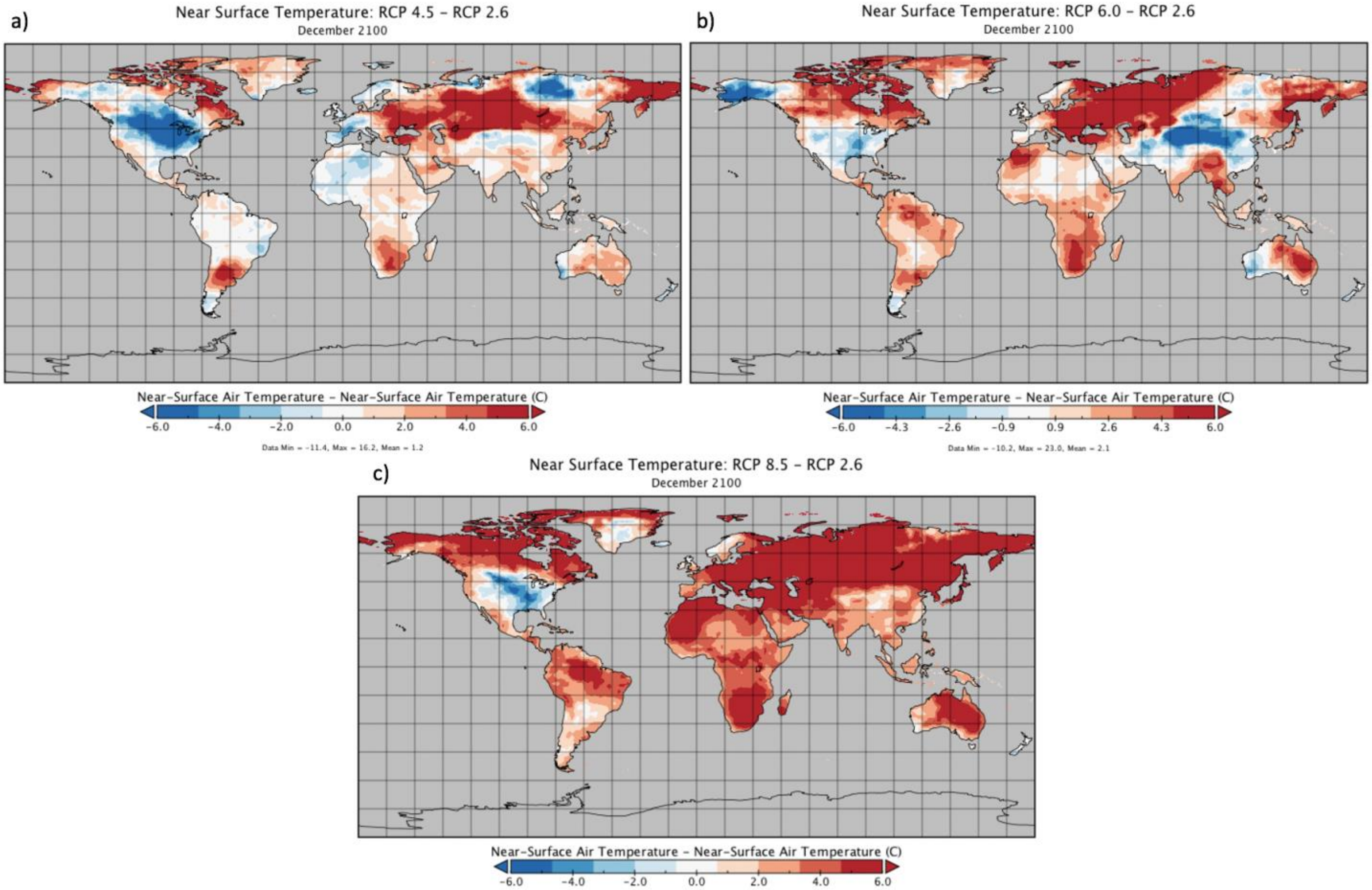


Figure 2 – Near surface temperature difference maps during December 2100 for a) RCP 4.5 – RCP 2.6 b) RCP 6.0 – RCP 2.6 c) RCP 8.5 – RCP 2.6. Red colors indicate locations where the RCP 2.6 scenario has lower temperatures, while blue colors indicate locations where the RCP 2.6 scenario has higher temperatures.

The maps in Figure 2 above are difference maps used to directly compare the RCP 4.5, RCP 6.0, and RCP 8.5 scenarios to the best-case scenario of RCP 2.6. In each map, the simulations from the RCP 2.6 scenario is subtracted from the other scenarios. For example, in Figure 2a the map was created by subtracting RCP 2.6 from RCP 4.5 (RCP 4.5 – RCP 2.6). All positive values in the map indicate the locations where the RCP 4.5 temperature is projected to be greater than then RCP 2.6 temperature. On the other hand, all negative values indicate locations where the RCP 4.5 temperature is projected to be less than then RCP 2.6 temperature. The same convection is used for Figure 2b and Figure 2c. Please note that all maps have the same scale.

Q6 (Same as Q1). Based on Figure 2 above, which RCP scenario (RCP 4.5, 6.0, or 8.5) leads to greater temperatures in South America by December 2100 when compared to the RCP 2.6 scenario?

RCP 8.5

Q7 (Same as Q2). Based on Figure 2 above, which RCP scenario (RCP 4.5, 6.0, or 8.5) leads to greater temperatures in Africa by December 2100 when compared to the RCP 2.6 scenario?

RCP 8.5

Q8 (Same as Q3). Based on Figure 2 above, which RCP scenario (RCP 4.5, 6.0, or 8.5) leads to lower temperatures in the United States by December 2100 when compared to the RCP 2.6 scenario?

RCP 4.5

Q9. Was Figure 1 or Figure 2 more useful in answering questions Q1 to Q3 (same as Q6 to Q8)? Why?

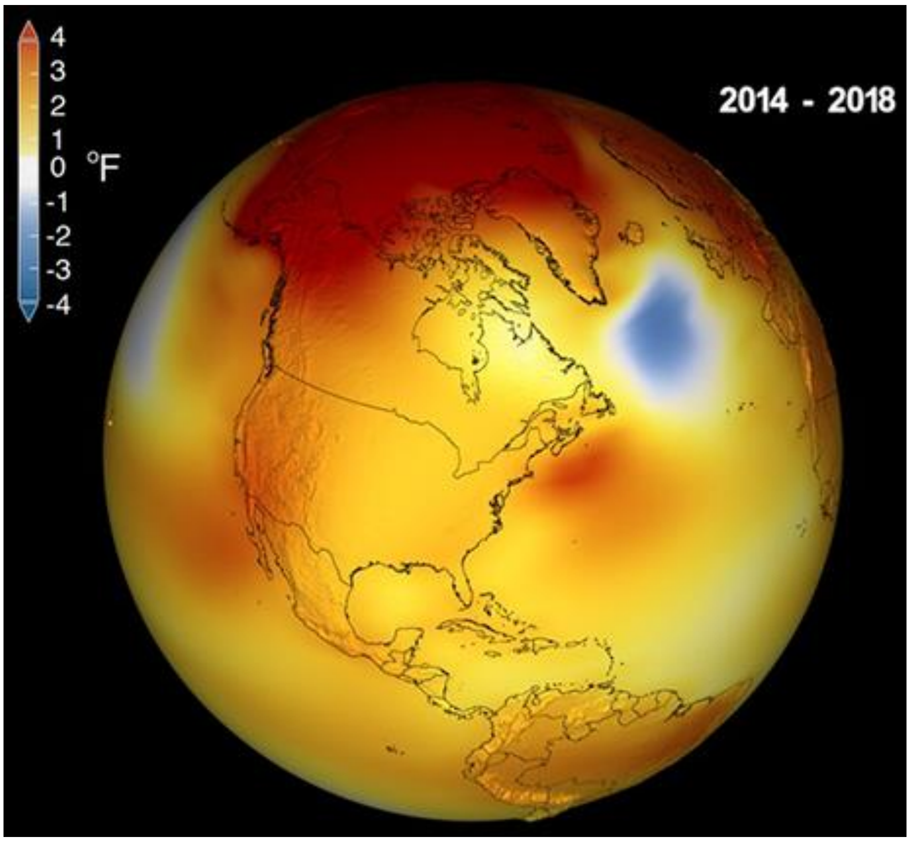
Figure 2 was more useful in answering the questions comparing the RCP 4.5, RCP 6.0, and RCP 8.5 scenarios to the RCP 2.6 scenario. When analyzing a difference map, small numerical differences in temperature are able to stand out. As stated in Q5, a 2-degree difference may seem small, but in terms of temperature, a 2-degree difference can have dramatic impacts. Difference maps allow for all changes in temperature, big or small, to show.

E. Conclusion and overview of linkages to next lesson and unit goals

In this lesson, the students learned about the different RCP scenarios global climate models use to make future projections based on different greenhouse gas emissions. The students also learned about the importance of using difference maps to effectively compare the simulations from the RCP temperature projections. In the next lesson, the students will download temperature projection simulations from the NASA GISS ModelE2 from the RCP 2.6, 4.5, and 8.5 scenarios and learn how to analyze the model output using RStudio. Specifically, the students will learn how to create average monthly temperature projection graphs based on three different 30-year intervals from 2011 to 2100 for New York City under the RCP 8.5 – 2.6 and RCP 4.5 – 2.6 scenarios. The goal is to learn how temperature is expected to change overtime under different RCP scenarios.

NASA Goddard Institute for Space Studies (GISS)
Climate Change Research Initiative (CCRI)
Applied Research STEM Curriculum Unit Portfolio

Unit Title: Future Temperature Projections
Lesson #2 Title: Using RStudio: Creating Temperature Projection Graphs for New York City
NASA STEM Educator / Associate Researcher: Nicole Dulaney
NASA PI / Mentor: Dr. Allegra N. LeGrande
NASA GSFC Office of Education – Code 160



VIII. Lesson #2: Using RStudio: Creating Temperature Projection Graphs For New York City

A. Summary and Goals of Lesson

In this lesson, the students will learn how to write a code in the R programming language using RStudio. The goal is for the students to learn how to analyze simulated future temperature projections from the GISS ModelE2 for the RCP 4.5 – 2.6 and RCP 8.5 – 2.6 scenarios for New York City. The lesson begins with the students downloading the RCP 2.6, 4.5, and 8.5 temperature projection model output and learning how to analyze netCDF output in RStudio. Specifically, the students will learn how to subtract model output in order to calculate the results from RCP 4.5 – 2.6 and RCP 8.5 – 2.6. Then, the students will learn how to subset the temperature projection output from 2011 to 2100 into three different 30-year intervals to ultimately analyze how temperature projections are expected to change at different time periods into the future. The students will also learn how to find monthly averages of each 30-year interval so they can analyze how the seasonal cycle is expected to be impacted by climate change. The lesson ends with the students learning how to create a line graph in RStudio to demonstrate the change in temperature projections overtime for the three different 30-year intervals for New York City. This analysis will be conducted for the RCP 4.5 – RCP 2.6 and RCP 8.5 – RCP 2.6 scenarios.

There is a For Teachers Guide available in this lesson that teachers are recommended to read before conducting the lesson. The guide discusses common challenge areas and specific components to look out for as students complete the lesson. The lesson also has example codes available for teacher use. The completion of this lesson is necessary for completion of the third lesson in the unit in which the students will use their knowledge of RStudio to analyze future monthly average temperature projections for the RCP 4.5 – RCP 2.6 and RCP 8.5 – RCP 2.6 scenarios for different cities around the world.

B. Table of Contents for lesson

C. 5 E Lesson Model Template

Teachers, please review the For Teachers Guide available after the lesson plan (before the RStudio Download Instructions) prior to allowing students to complete this lesson.

STEM Earth Science Research

Unit: Future Temperature Projections **Topic**: Using RStudio: Creating Temperature Projection Graphs for NYC

Prior Learning: For successful completion of this lesson, the students should have knowledge of the different magnitude of climate forcing in the future RPC scenarios of RCP 2.6, 4.5, and 8.5 discussed in Lesson #1 of this unit. The students should also understand the importance of calculating the differences between each scenario for analysis, such as RCP 4.5 – 2.6 and RCP 8.5 – 2.6, rather than analyzing values from each RCP scenario individually. In this lesson, the students will learn how to create plots that show monthly temperature averages for three different 30-year intervals from 2011 to 2100 for New York City. The students will create a total of two plots; one for the RCP 4.5 – 2.6 difference scenario and one for the RCP 8.5 – 2.6 difference scenario. This lesson will prepare the students for Lesson #3 where they will create time series plots for temperature projections for specific cities around the world. The students will then prepare an oral presentation teaching the class about the climate of their city, and how climate change is expected to impact their city.

Warm Up Activity (Pre-Assessment):

1. Predict which months of the year will experience the greatest changes in temperature in New York City out to the year 2100.

2. In general, predict how you expect temperature to change in New York City by the year 2100.

Aim: How can we create monthly temperature projection plots in RStudio?

New York State Standards:

1.1f - Earth's changing position with regard to the Sun and the moon has noticeable effects.

- Earth revolves around the Sun with its rotational axis tilted at 23.5 degrees to a line perpendicular to the plane of its orbit, with the North Pole aligned with Polaris.
- During Earth's one-year period of revolution, the tilt of its axis results in changes in the angle of incidence of the Sun's rays at a given latitude; these changes cause variation in the heating of the surface. This produces seasonal variation in weather.

2.2a - Insolation (solar radiation) heats Earth's surface and atmosphere unequally due to variations in:

- the intensity caused by differences in atmospheric transparency and angle of incidence which vary with time of day, latitude, and season
- characteristics of the materials absorbing the energy such as color, texture, transparency, state of matter, and specific heat
- duration, which varies with seasons and latitude.

Next Generation Science Standards:

HS - ESS2-4 - Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate.

HS - ESS3-5 - Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth systems.

Common Core State Standards:

CCSS: 9-10.RST.3 - Follow precisely a multistep procedure when carrying out experiments, taking measurements, or performing technical tasks.

CCSS: 9-10.RST.7 - Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem.

NASA System Engineering Behavior:
Technical Acumen:
1a. Possesses Technical Competence and Has Comprehensive Previous Experience
1b. Learns from Successes and Failures
Problem Solving & Systems Thinking:
2a. Thinks Systematically
2b. Possess Creativity and Problem-Solving Abilities

Performance Objective: Students will be able to create average monthly temperature projection plots of three 30-year intervals for the RCP 8.5 – 2.6 and RCP 4.5 – 2.6 scenarios by completing a step-by-step guide that outlines how to analyze netCDF output in RStudio.

Students will be able to evaluate how temperature projections will change over the course of three different 30-year intervals by analyzing their projection graphs for New York City through guided questions in the activity.

Materials: GISS ModelE2 projection simulations; Rstudio; Class set of computers

Links to electronic sources are provided below:

- GISS ModelE2 Projection Simulations: ftp://gdo-dcp.ucllnl.org/pub/dcp/archive/cmip5/global_mon/BCSD/giss-e2-r/
    - The link above cannot be a descriptive link because it must be copied and pasted exactly as is into a browser.
- Link to RStudio program download

Vocabulary: No new vocabulary.

Anticipatory Opening: Discuss with the students what a climate model is and how climate scientists write computer code to analyze model output efficiently.

Development of the Lesson: Approximately Eight-Day Lesson (Eight 50-minute periods).

Teachers, please review the For Teachers Guide available after the lesson plan (before the RStudio Download Instructions) prior to allowing students to complete this lesson.

What the teacher does	What the student does	Time
1. Write down the Warm Up Activity, Aim, and the HW on the blackboard.		
2. Circulate the room while the students complete the Warm Up Activity questions. The questions assess the students' ability to predict how climate change will influence temperature projections specifically for New York City. ***Assessment Opportunity #1 (Student prior knowledge from previous units)***	The students answer the Warm Up Activity questions in their notebooks by making predictions as to how temperature will change overtime in New York City.	**5 min**
3. ENGAGE Discuss how scientists use climate models and coding to efficiently analyze an abundant amount of output Also introduce the concept of a seasonal cycle to the students. This is simply a comparison of model output, such as temperature, on a month-to-month basis.	The students learn how scientists use climate models and coding to efficiently analyze an abundant amount of model output. The students learn what is meant by the term "seasonal cycle".	**10 min**
4. EXPLORE & EXPLAIN Introduce the students to RStudio. Circulate the room as the students complete the guided activity that shows them how to write a code and perform calculations in RStudio. Look for common challenges and misconceptions in the guided activity, specifically from answers to questions **Q1 to Q15. These questions serve as check for understanding questions and should be evaluated by the teacher throughout the activity.** ***Assessment Opportunity #2 (Student answers to questions Q1 to Q15 of the activity)*** ***Assessment Opportunity #3 (Student-created RCP 4.5 – 2.6 scenario temperature projection plot).***	The students begin the RStudio guided activity by learning how to write a code that reads in netCDF output. The students learn how to extract variables from netCDF output and how to trim down model output based on specific latitude and longitude coordinates. The students answer questions Q1 to Q15 throughout the guided activity. These questions serve as check for understanding questions. The students use the guide to create a monthly time series plot for three 30-year intervals of temperature projections for the RCP 4.5 – 2.6 scenario.	**4 periods**

What the teacher does	What the student does	Time
5. ELABORATE & EVALUATE Circulate the room as the students use RStudio to answer the Elaborate and Evaluate questions at the end of the RStudio guided activity. ***Assessment Opportunity #4 (Student answers to the elaborate & evaluate questions)***	The students write a new code to create the RCP 8.5 – 2.6 temperature projection plot for New York City with little guidance. Students need to elaborate on their knowledge of the guide to create this plot. The students answer questions Q16 to Q24 of the activity.	**3 periods**
6. Administer the Daily Formative Assessment (DFA) to the students. This DFA will show whether the students learned from/expanded on their answers to the Warm Up Activity. ***Assessment Opportunity #5 (Student answers to the DFA).***	The students individually answer questions for the Daily Formative Assessment. The students will submit their answers at the end of class.	**10 min**

Summary/Conclusion: The students individually answer questions for the Daily Formative Assessment. The students will submit their answers at the end of class.

Higher Order Questions:

See the questions Q1 – Q24 in the RStudio guided activity.

Differentiated Instruction:

- The students are exposed to content in written, oral, and visual forms (multiple modalities exist).
- Students can use colored pencils to draw diagrams and annotate notes in a way that is meaningful to them.
- Students are asked both higher and lower level questions so all students can answer questions at their particular academic level.
- Students are given time to answer questions during think pair share/group activities.
- Students are provided with screenshots of the correct code throughout the RStudio guided activity to help ensure they are on the right track.
- Students who need extra support can join the teacher for small group instruction and more efficient feedback.
- Students who are performing at a higher level can complete the tasks provided in the For Further Exploration part of the lesson plan.

- Students who are visually impaired can be provided with the text of the example codes the teachers are given in the lesson plan to check their progress. This will help students who will not benefit from the screenshots of correct code provided throughout the activity.

Daily Formative Assessment:

1. Explain how monthly temperature is expected to change in New York City across the three different 30-year intervals for the RCP 4.5 – 2.6 and RCP 8.5 – 2.6 scenarios.

Next Lesson: The next lesson the students will use their new knowledge of creating plots in RStudio to work in a group to prepare an oral presentation based on future temperature projections of a given city.

For Further Exploration:

Students who could use a challenge and show that they are strong coders can try the Coding Challenges Activity found at the end of the lesson plan. The Coding Challenges Activity presents students with coding tasks in RStudio that go beyond what was taught in the RStudio guide.

Documents in Lesson Plan in Order of Appearance:

1. RStudio Download Instructions
2. For Teachers Guide
3. Functions.R Script
4. Using RStudio: Creating Temperature Projection Graphs for New York City
5. Example RScript – RCP 4.5 – 2.6 Temperature Projection Graphs
6. Example RScript – RCP 8.5 – 2.6 Temperature Projection Graphs
7. Coding Challenges Activity
8. Data Table for Longitude, Latitude, and Time Grid Boxes

Notes For Revision:

D. Supporting Documents (order according to sequence of lesson)

RStudio Download Instructions

Step 1. To download RStudio, the computer must have a program called R installed first. [To download R, click on this link.] Then, you should see a screen titled The Comprehensive R Archive Network with options to download R for the type of computer you have. This screen is shown in the image below.

The Comprehensive R Archive Network

Download and Install R

Precompiled binary distributions of the base system and contributed packages, **Windows and Mac** users most likely want one of these versions of R:

- Download R for Linux
- Download R for (Mac) OS X
- Download R for Windows

R is part of many Linux distributions, you should check with your Linux package management system in addition to the link above.

Choose the download option based on the computer you have.

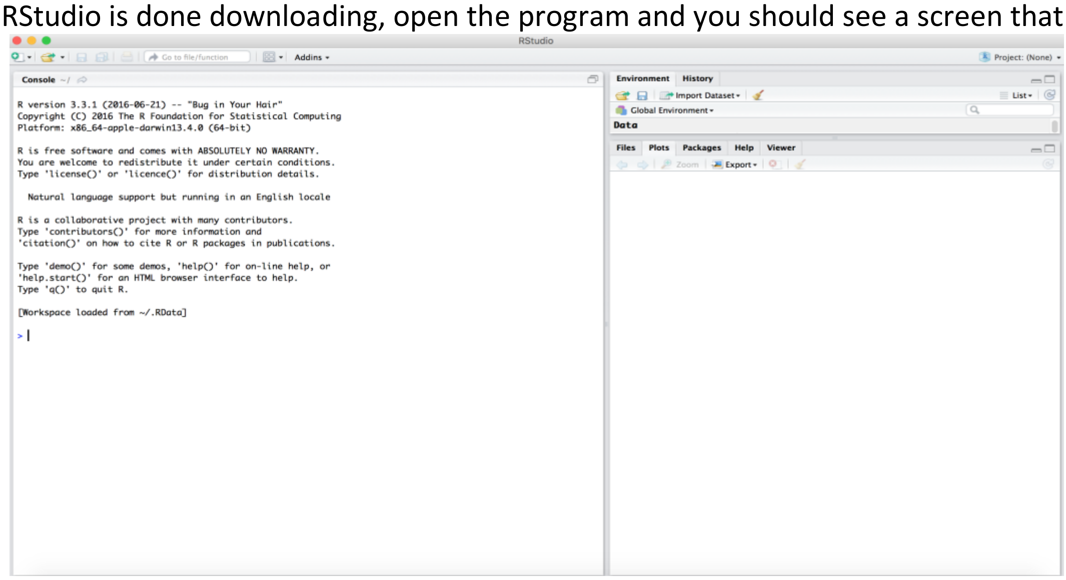
Step 2. Once R is downloaded and installed, [click on this link to download RStudio.]

Scroll down to the section on the page titled **Installers for Supported Platforms and focus on the section labeled Installers as shown in the image below:**

Installers	Size	Date	MD5
RStudio 1.0.136 - Windows Vista/7/8/10	81.9 MB	2016-12-21	93b3f307f567c33f7a4db4c114099b3e
RStudio 1.0.136 - Mac OS X 10.6+ (64-bit)	71.2 MB	2016-12-21	12d6d6ade0203a2fcef6fe3dea65c1ae
RStudio 1.0.136 - Ubuntu 12.04+/Debian 8+ (32-bit)	85.5 MB	2016-12-21	0a20fb89d8aaeb39b329a640ddadd2c5
RStudio 1.0.136 - Ubuntu 12.04+/Debian 8+ (64-bit)	92.1 MB	2016-12-21	2a73b88a12a9fbaf96251cecf8b41340
RStudio 1.0.136 - Fedora 19+/RedHat 7+/openSUSE 13.1+ (32-bit)	84.7 MB	2016-12-21	fa6179a7855bff0f939a34c169da45fd
RStudio 1.0.136 - Fedora 19+/RedHat 7+/openSUSE 13.1+ (64-bit)	85.7 MB	2016-12-21	2b3a148ded380b704e58496befb55545

Click on the option based on the computer that you have.

Step 3. When RStudio is done downloading, open the program and you should see a screen that looks like this:



For Teachers Guide

Meaning of highlighted text:

- Purple means the text is related to Functions.R
- Yellow means the text provides essential information for both students and teachers
- Blue means the text is for teachers only

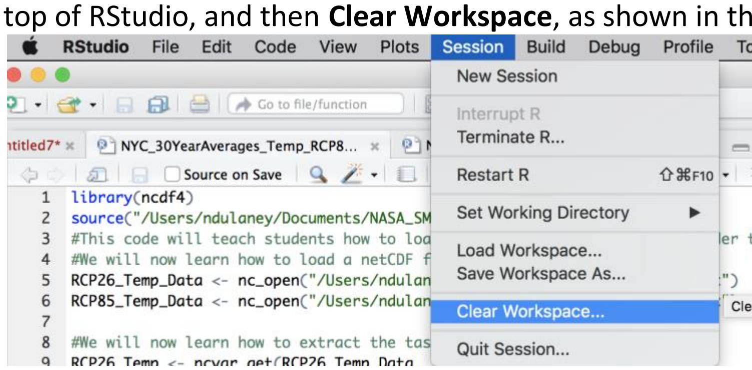
Directions: Please read this **For Teachers Guide** in entirety before presenting students with the **Using RStudio: Creating Temperature Projection Graphs for New York City** activity. This guide presents helpful hints, shortcuts, and possible challenges students can experience throughout the activity.

Hint #1. The **Using RStudio: Creating Temperature Projection Graphs for New York City** activity begins with the students downloading the RCP 2.6, RCP 4.5, and RCP 8.5 temperature model output from [the GISS ModelE2 found at this link.](ftp://gdo-dcp.ucllnl.org/pub/dcp/archive/cmip5/global_mon/BCSD/giss-e2-r/) However, the link must be copied & pasted in a browser to access. The full link is ftp://gdo-dcp.ucllnl.org/pub/dcp/archive/cmip5/global_mon/BCSD/giss-e2-r/

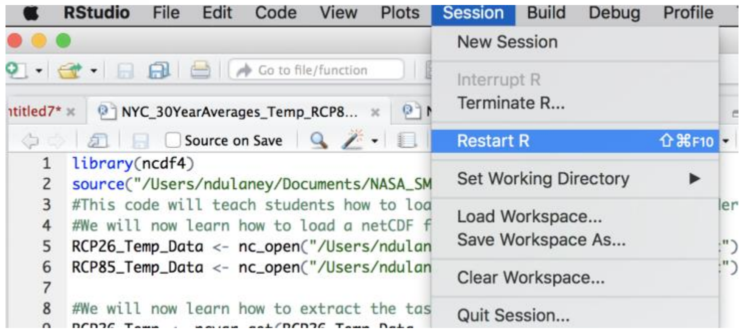
To save time during class, it is recommended that the teacher downloads the model output in advance and already has it named with the proper naming convention. Then, the teacher can send the model output to the students through email, Google Classroom, or another feasible method for the students to download onto their own computers. The output can take a long time to download, and it is recommended that students begin downloading at the beginning of class. If output is downloaded in advance, students can skip the Model Output Download portion of the **Using RStudio: Creating Temperature Projection Graphs for New York City** activity.

Hint #2. The model output files are very large and can take up a lot of memory in RStudio. Once the files are loaded for the first time into RStudio, students do not need to keep running the lines of code that load in the model output (lines #5 & #6). Every time a student re-loads the model output into RStudio, they are using unnecessary memory.

Hint #3. If the students do ultimately receive an error message in the Console about limited memory, have them go to **Session** at the top of RStudio, and then **Clear Workspace**, as shown in the image below.



Then, have them Restart R by going to **Session** and then **Restart R**, as shown image below.



Students will then have to re-run their RScript from the beginning. After the students load in the model output, please remind them that they do not have to keep re-loading the output!

Hint #4. The model output students are working with in this activity is in the form of netCDF and is structured in terms of grid boxes. Each latitude, longitude, and time component of the dataset is assigned a specific grid box number that corresponds to a value. The netCDF output used in this activity contains 720 longitude grid boxes, 278 latitude grid boxes, and 1,140 time grid boxes to represent temperature at a specific location at a given time slice.

The grid box numbers for latitude and longitude do not directly correspond to a location's latitude and longitude measurements. To help students correctly specify the latitude and longitude grid boxes for a given location, two functions were created in a separate RScript titled **Functions.R**. Going forward in this **For Teachers Guide** and the **Using RStudio: Creating Temperature Projection Graphs for New York City** activity, any item highlighted in purple is related to a function created in **Functions.R**.

The RScript **Functions.R** needs to be provided to the students to download at the start of the activity. Step #25 of the activity tells students how to access the functions within **Functions.R.** Furthermore, steps #25 to #29 of the activity tells students how to use the functions **LatGrid**, **LonGrid_West**, and **LonGrid_East** found within **Functions.R**.

For more information on how the functions **LatGrid**, **LonGrid_West**, and **LonGrid_East** were created, please view the **Functions.R** script on the next page of this lesson and read all of the commented statements that accompany each function.

Hint #5. There are additional functions in **Functions.R,** such as **MonYearGrid** and **Months_Data**, to further help students navigate the netCDF output and to ensure their codes run efficiently. **MonYearGrid** allows students to input a month and year and the result is the proper time grid box number. **Months_Data** allows users to determine which months out of the 1,140 time slices correspond to January, February, March, etc.

For more information on how the functions **MonYearGrid** and **Months_Data** were created, please view the **Functions.R** script on the next page of this lesson and read all of the commented statements that accompany each function.

Note: The Functions.R script is available on the next page after this For Teachers Guide.

Hint #6. At the end of this entire lesson there is a document titled **Data Table for Longitude, Latitude, and Time Grid Boxes.** The data table contains latitude and longitude measurements and month-year combinations that correspond to their grid box values. Although the functions in **Functions.R** can be used to determine the proper grid box values, this data table is available for teachers to access, if necessary.

Hint #7. Remind students that anything they are asked to do in the Console of RStudio **must be typed** and not copied and pasted from the instructions. When text is copied and pasted into the Console, the commands do not work the same.

Functions.R Script

Meaning of highlighted text:

- Purple means the text is related to Functions.R
- Yellow means the text provides essential information for both students and teachers
- Blue means the text is for teachers only

Copy and paste the code below into an RScript and save it as Functions.R This needs to be provided to the students for download at the beginning of the Using RStudio: Creating Temperature Projection Graphs for New York City activity

```
# Functions are programming ways to make a 'short cut' of tasks that need to be done several times. They are like the refrain from a song -- once you have written it out, you can recall all of its pieces by just calling the function name.
#There are built-in functions and user-defined (you make it!) functions.
#The function LatGrid below is a user-defined function designed to read in a value representing latitude, denoted as Lat, to provide the corresponding grid box value, denoted as jlat.
#Once the function is created, a user can determine a grid box for a specific latitude by typing LatGrid(Lat), with lat being a specific latitude value.
LatGrid<-function(Lat,npar=TRUE,print=TRUE){ #npar=TRUE is used to tell RStudio that there can be any number of parameters used in the function. print=TRUE is used to tell RStudio you will be printing the result of the function
    # Variables can make it easier to make changes to your code later on. Let's define a few here:
  Lat_Res<-0.5 #This represents the resolution (interval) of the latitudes of the datasets. This means latitude has an interval of 0.5 degrees
  Lat1<--55.25  #This is the first latitude value in the dataset. -55.25˚ represents 55.25˚S latitude
  # R has built in functions to help you with your programming. We will use the built-in R functions 'seq' and 'round'
  Lat_Edges<-seq(-55.75,83.75,Lat_Res) #This creates a sequence of all of the latitude values in the dataset, including 0.5 degrees above the highest latitude and 0.5 degrees below the lowest latitude. Lat_Edges contains all values from -55.75 to 83.75 at an interval of 0.5
  All_Lats<-seq(Lat1,83.25,0.5) #This creates a sequence of all of the latitude values in the dataset.
  jlat<-round((Lat+55.75)/0.5) #This takes the input value of the function, Lat, and assigns it the proper grid box value
  # The built-in paste function lets you print out many things on the same line
  print(paste("Gridpoint",jlat,"is ~ Latitude",All_Lats[jlat]
```

```
            ,"degrees North; bounded by",Lat_Edges[jlat],"degrees North
and"
            ,Lat_Edges[jlat+1],"degrees North"),sep=" ") #This is
printed after a user utilizes the function LatGrid. The result is the grid
box value for the latitude input into LatGrid, followed by the latitude
value of the dataset that is closest to the input latitude in
LatGrid(lat), and the latitude values bounded above and below.
  return(jlat)
}

#The function LonGrid_East below is built to read in a value representing
longitude representing degrees East, denoted as Lon_East, to provide the
corresponding grid box value, denoted as jlon_east.
#Once the function is created, a user can determine a gridbox for a
specific east longitude by typing LonGrid_East(Lon_East), with Lon_East
being a specific east longitude value.
LonGrid_East<-function(Lon_East,npar=TRUE,print=TRUE){
  Lon_Res<-0.5 #This represents the resolution (interval) of the
longitudes of the datasets. This means longitude has an interval of 0.5
  Lon1<-0.25  #This is the first longitude value in the dataset. 0.25˚
represents 0.25˚E longitude
  seq1_Edges<-seq(0,180,Lon_Res) #This creates a sequence of numbers from
0 to 180 that goes by 0.5, the longitude resolution.
  seq2_Edges<-seq(-180,0,Lon_Res) #This creates a sequence of numbers from
-180 to 0 that goes by 0.5, the longitude resolution.
  Lon_Edges<-c(seq1_Edges,seq2_Edges) #The combines the two sequences
(seq1a & seq2a) into one sequence. This sequence includes all longitude
values in the dataset, including 0.5 degrees above the highest longitude
and 0.5 degrees below the lowest longitude. Lon_Edges contains all values
from -180 to 180 at an interval of 0.5
  seq1_All<-seq(0.25,179.75,Lon_Res) #This creates a sequence of numbers
from 0.25 to 179.75 that goes by 0.5, the longitude resolution.
  seq2_All<-seq(-179.75,-0.25,Lon_Res) #This creates a sequence of numbers
from -179.75 to -0.25 that goes by 0.5, the longitude resolution.
  All_Lons<-c(seq1_All,seq2_All) #The combines the two sequences (seq1b &
seq2b) into one sequence. This sequence includes all longitude values in
the dataset.
  jlon_east<-round((Lon_East+0.5)/0.5) #This takes the input value of the
function, Lon_East, and assigns it the proper grid box value. This only
works for longitudes that measure degrees East.
  print(paste("Gridpoint",jlon_east,"is ~ Longitude",All_Lons[jlon_east]
            ,"degrees East; bounded by",Lon_Edges[jlon_east],"degrees
East and"
            ,Lon_Edges[jlon_east+1],"degrees East"),sep=" ") #This is
printed after a user utilizes the function LonGrid_East. The result is the
grid box value for the east longitude input into LonGrid, followed by the
```

```
longitude value of the dataset that is closest to the input longitude in
LonGrid_East(Lon_East), and the longitude values bounded above and below.
  return(jlon_east)
}

#The function LonGrid_West below is built to read in a value representing
longitude representing degrees West, denoted as Lon_West, to provide the
corresponding grid box value, denoted as jlon_west.
#Once the function is created, a user can determine a gridbox for a
specific west longitude by typing LonGrid_West(Lon_West), with Lon_West
being a specific west longitude value.
LonGrid_West<-function(Lon_West,npar=TRUE,print=TRUE){
  Lon_Res<-0.5 #This represents the resolution (interval) of the
longitudes of the datasets. This means longitude has an interval of 0.5
  Lon1<-0.25  #This is the first longitude value in the dataset. 0.25˚
represents 0.25˚E longitude
  seq1_Edges<-seq(0,180,Lon_Res) #This creates a sequence of numbers from
0 to 180 that goes by 0.5, the longitude resolution.
  seq2_Edges<-seq(-180,0,Lon_Res) #This creates a sequence of numbers from
-180 to 0 that goes by 0.5, the longitude resolution.
  Lon_Edges<-c(seq1_Edges,seq2_Edges) #The combines the two sequences
(seq1a & seq2a) into one sequence. This sequence includes all longitude
values in the dataset, including 0.5 degrees above the highest longitude
and 0.5 degrees below the lowest longitude. Lon_Edges contains all values
from -180 to 180 at an interval of 0.5
  seq1_All<-seq(0.25,179.75,Lon_Res) #This creates a sequence of numbers
from 0.25 to 179.75 that goes by 0.5, the longitude resolution.
  seq2_All<-seq(-179.75,-0.25,Lon_Res) #This creates a sequence of numbers
from -179.75 to -0.25 that goes by 0.5, the longitude resolution.
  All_Lons<-c(seq1_All,seq2_All) #The combines the two sequences (seq1b &
seq2b) into one sequence. This sequence includes all longitude values in
the dataset.
  jlon_west<-round((Lon_West+360)/0.5) #This takes the input value of the
function, Lon_West, and assigns it the proper grid box value. This only
works for longitudes that measure degrees West.
  print(paste("Gridpoint",jlon_west,"is ~ Longitude",All_Lons[jlon_west]
              ,"degrees East; bounded by",Lon_Edges[jlon_west],"degrees
East and"
              ,Lon_Edges[jlon_west+1],"degrees East"),sep=" ") #This is
printed after a user utilizes the function LonGrid_West. The result is the
grid box value for the west longitude input into LonGrid_West, followed by
the west longitude value of the dataset that is closest to the input
longitude in LonGrid_West(Lon_West), and the longitude values bounded
above and below.
  return(jlon_west)
}
```

```
#The function MonYearGrid below is built for users to input a specific
month & year to get the proper time grid box value for that month & year.
library(zoo) #The zoo library is needed for the function MonYearGrid to
run. The zoo package must already be installed.
MonYearGrid <- function(MonYear,npar=TRUE,print=TRUE){ #This is creating
function MonYearGrid. MonYear will be the input month & year and the
result will be the proper time grid box value
  my1 <- as.yearmon(as.character(200601), "%Y%m") #This takes the first
month & year of the dataset, 200601 (January 2006), and converts it to Jan
2006
  my2 <- as.yearmon(as.character(210012), "%Y%m") #This takes the last
month & year of the dataset, 210012 (December 2100), and converts it to
Dec 2100
  s <- c(seq(my1, my2, 1/12)) #This uses the seq command to create a
sequence of all month & years from Jan 2006 to Dec 2100. All months are
shortened to their first three letters.
  time <- which(s==MonYear) #This uses the command "which" that will
return the time grid box value for the specified input MonYear
  return(time)
}

#The function Months_Data below is built to read in a number representing
a specific month (January=1, February=2, for example) and assign all time
grid box values that correspond to that month.
#For example, since there are 12 months in a year, time grid box
1,13,25,etc correspond to January months.
#Once the function is created, a user can group all of the time grid boxes
assigned to each month together by inputting a number from 1 to 12 as
Mon_num in the function Months_Data(Mon_num)
Months_Data <- function(Mon_num,npar=TRUE,print=TRUE){
  Month <- seq(Mon_num,360,12) #This creates a list of all time grid box
values that correspond to the specified number from 1 to 12 input as
Months_num.
  return(Month)
}
```

Using RStudio: Creating Temperature Projection Graphs for New York City

Meaning of highlighted text:

- Purple means the text is related to Functions.R
- Yellow means the text provides essential information for both students and teachers
- Blue means the text is for teachers only

Activity Description: The purpose of this activity is for the students to learn how to write a code in RStudio that will allow them to create time series line graphs that show average monthly temperature projections for the RCP 4.5 – 2.6 and RCP 8.5 – 2.6 scenarios. The students will be evaluating temperature projections in 30-year subsets. The students will learn how to load netCDF data into RStudio, how to extract variables from the datasets, how to subset the data based on latitude and longitude coordinates for a specific city, and how to plot average monthly data in 30-year subsets.

NOTE: Lesson #1 titled ***Representative Concentration Pathways (RCP)*** needs to be completed prior to this activity.

Model Output Download

Step 1. We will first begin by downloading the RCP 2.6 temperature model output. ***Copy & paste*** the following link into your browser ftp://gdo-dcp.ucllnl.org/pub/dcp/archive/cmip5/global_mon/BCSD/giss-e2-r/ and click on the option titled **rcp26/** as shown in the image below. ***(Note: Full link is provided because it must be copied and pasted in a browser)***

Index of /pub/dcp/archive/cmip5/global_mon/BCSD/giss-e2-r/

[parent directory]

Name	Size	Date Modified
historical/		7/3/12, 8:00:00 PM
rcp26/		7/3/12, 8:00:00 PM
rcp45/		7/3/12, 8:00:00 PM
rcp60/		7/3/12, 8:00:00 PM
rcp85/		7/3/12, 8:00:00 PM

Then, click on **mon**, and then **r1i1p1**, where you will be led to this screen shown in the image below.

Index of /pub/dcp/archive/cmip5/global_mon/BCSD/giss-e2-r/rcp26/mon/r1i1p1/

[parent directory]

Name	Size	Date Modified
pr/		7/10/12, 8:00:00 PM
tas/		7/4/12, 8:00:00 PM
tasmax/		7/4/12, 8:00:00 PM
tasmin/		7/4/12, 8:00:00 PM

Step 2. Click on the variable titled **tas,** which stands for **temperature**. Click on **tas** and you will then see a screen like the one in the image below. This screen shows the full name of the temperature dataset we want to download.

Index of /pub/dcp/archive/cmip5/global_mon/BCSD/giss-e2-r/rcp26/mon/r1i1p1/tas/

[parent directory]

Name	Size	Date Modified
BCSD_0.5deg_tas_Amon_GISS-E2-R_rcp26_r1i1p1_200601-210012.nc	223 MB	7/4/12, 8:00:00 PM

Click on the link provided to download the future temperature projection output for the RCP 2.6 scenario.

Step 3. This dataset should now be in the Downloads folder of your computer. The filename is very long and it would be best to rename it. Go to the Downloads folder, right click on the dataset, and choose to rename the dataset **RCP26_Temperature.nc** **(Note: The .nc extension is necessary to denote a netCDF file)**

Step 4. To download model output from the RCP 4.5 scenario, we need to navigate back to the page with all of the RCP scenarios. To do this, click on "**parent directory**" in the top left corner as outlined in the image below.

Index of /pub/dcp/archive/cmip5/global_mon/BCSD/giss-e2-r/rcp26/mon/r1i1p1/tas/

[parent directory]

Name	Size	Date Modified
BCSD_0.5deg_tas_Amon_GISS-E2-R_rcp26_r1i1p1_200601-210012.nc	223 MB	7/4/12, 8:00:00 PM

Then, keep clicking "**parent directory**" until you are back to the page with all of the RCP scenarios.

Step 5. Once you are back to the page with all of the RCP scenarios, click **on rcp45/** as shown in the image below.

Index of /pub/dcp/archive/cmip5/global_mon/BCSD/giss-e2-r/

[parent directory]

Name	Size	Date Modified
historical/		7/3/12, 8:00:00 PM
rcp26/		7/3/12, 8:00:00 PM
rcp45/		7/3/12, 8:00:00 PM
rcp60/		7/3/12, 8:00:00 PM
rcp85/		7/3/12, 8:00:00 PM

Then, click on **mon**, and then **r1i1p1**, where you will be led to this screen shown in the image below.

Index of /pub/dcp/archive/cmip5/global_mon/BCSD/giss-e2-r/rcp45/mon/r1i1p1/

[parent directory]

Name	Size	Date Modified
pr/		7/10/12, 8:00:00 PM
tas/		7/4/12, 8:00:00 PM
tasmax/		7/4/12, 8:00:00 PM
tasmin/		7/4/12, 8:00:00 PM

Click on the variable titled **tas,** which stands for temperature. Click on **tas** and then the link provided to download **temperature** output for RCP 4.5.

Step 6. Go to the Downloads folder, right click on the dataset, and rename the dataset **RCP45_Temperature.nc**

Step 7. To download output from the RCP 8.5 scenario, we need to navigate back to the page with all of the RCP scenarios. To do this, click on "**parent directory**" in the top left corner of the page and keep clicking "**parent directory**" until you are back to the page with all of the RCP scenarios.

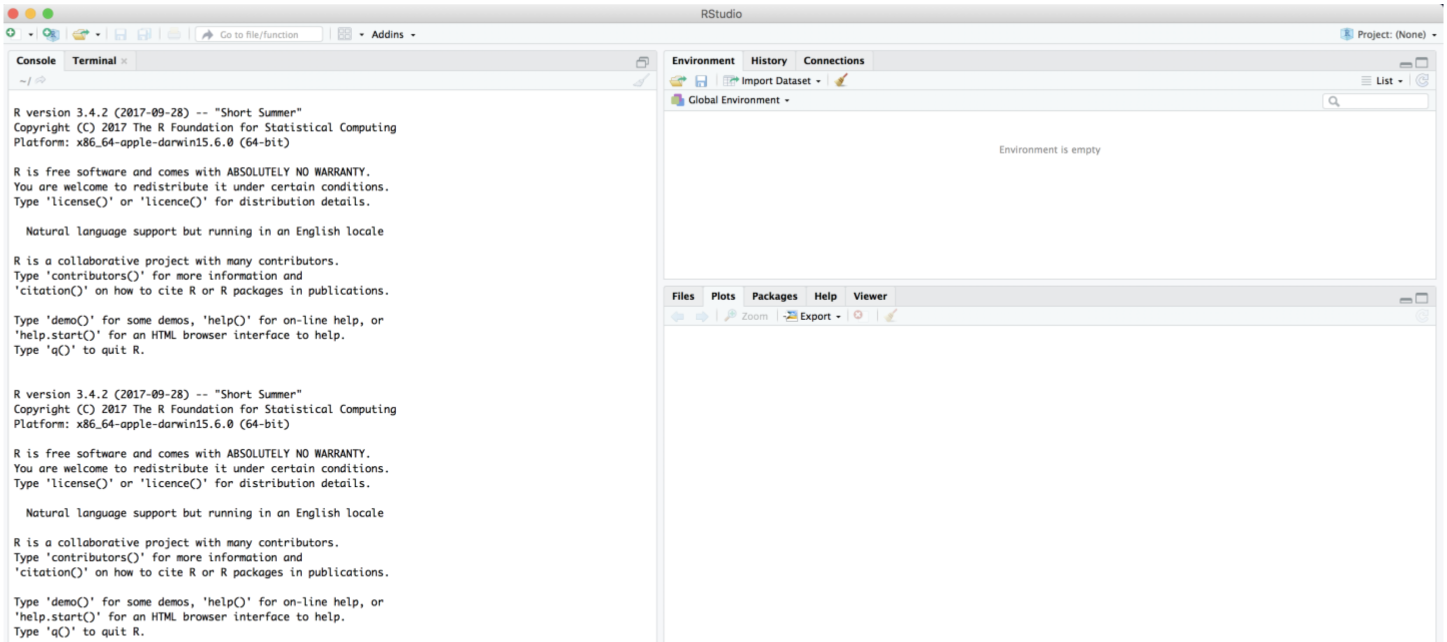
Once you are back to the page with all of the RCP scenarios, click **on rcp85/**, then **mon**, **r1i1p1**, **tas**, and then the link to download the model output.

Go to the Downloads folder, right click on the dataset, and rename the dataset **RCP85_Temperature.nc**

RStudio Activity

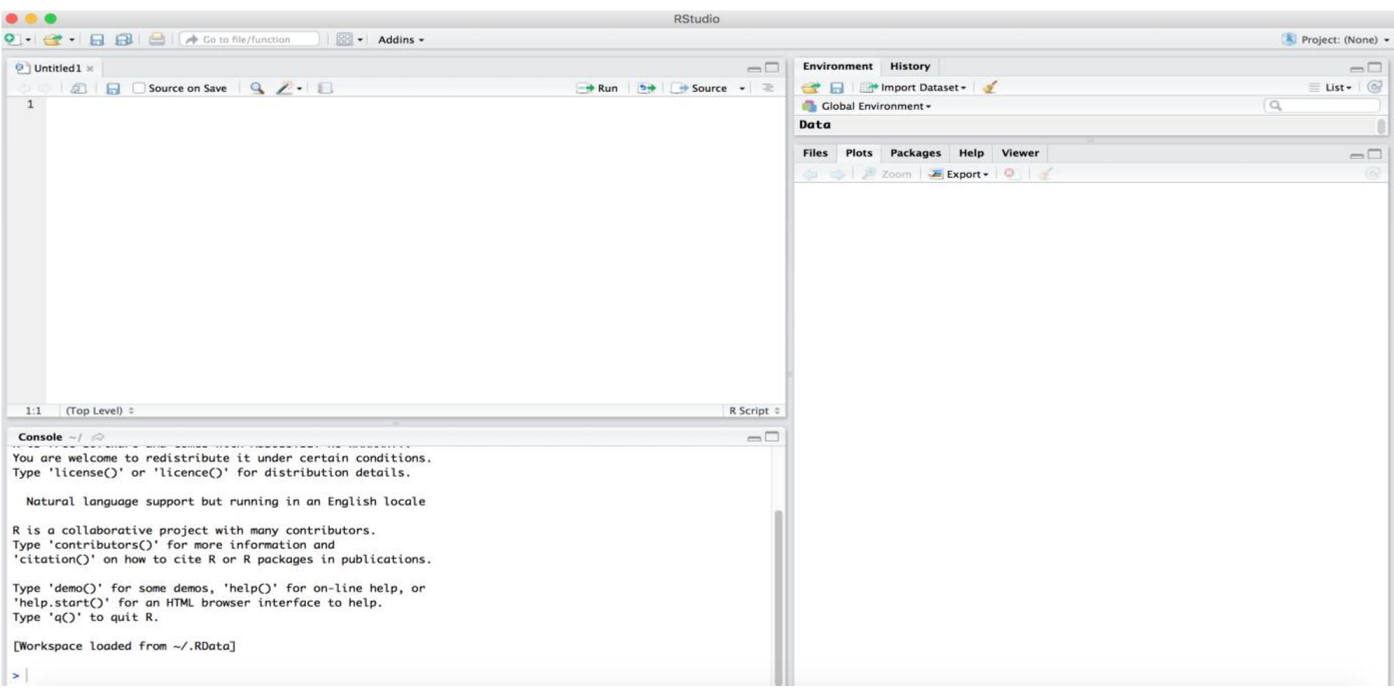
Step 1. Ensure that Rstudio is installed on your computer. If RStudio is not downloaded on your computer, please view the download instructions provided before this activity.

Step 2. Open RStudio and you will see a screen that looks like this.



Step 3. At the top left of Rstudio, click on **File**, then **New File,** and then click **R Script**.

Step 4. You should now see the following on your screen in the image below. The image shows a blank script in the top left of the program, and now the Console is on the bottom left of the program.



Step 5. The ***top left panel*** of RStudio contains the **R Script** that will be used to write code with the R programming language. Once a script is created, a user can run the entire script or run the script line by line or section by section.

The ***bottom left panel*** of RStudio contains the **Console** which displays the lines of code that the user selects to run. Users can also type commands and perform calculations directly in the **Console** for a quick answer rather than writing a script and waiting for an answer after running the script.

The ***top right side*** of RStudio contains an **Environment tab** which lists all of the datasets that have been loaded into RStudio. There is also a **History tab** that contains the history of everything that was typed into the **Console**.

The ***bottom right side*** of RStudio contains a **Plot tab** that allows users to look at any plots that are created. There is a **Packages tab** that allows users to download packages that are needed for specific R tasks, and there is a **Help tab** that allows users to search how to use specific commands in R.

Step 6. When RStudio is first downloaded, it comes with a default set of commands. Commands can help users accomplish tasks or calculations that are not simple addition and subtraction. To work with netCDF data and associated commands in Rstudio, users need to install the **ncdf4** library.

Go to the **Console** and ***type*** install.packages("ncdf4") and then press enter. The library package will download in the **Console**.

You will also need another package called **zoo** later in this activity. You can download it now by typing **install.packages("zoo")** in the Console.

Step 7. Once a library is downloaded, it does not need to be downloaded again. However, it does need to be referenced at the top of every R Script that uses the **ncdf4 library**. It is always a great idea to reference the libraries needed in each script at the top of the code.

On line #1 of your R Script, type library(ncdf4). Library is a command in line #1 and there, you are referencing the **ncdf4 library** with the library command.

Step 8. Most coders (individuals who write code) begin the code by writing at the top of the script what the code will be about. The description of the code needs to be "commented out", which means the writing will not be part of the code when the code is later running.

In the R language, the symbol "#" needs to be placed in the beginning of each line of the code that is meant to be commented out. For example:

#This statement is written to teach students how to comment out a line in a R code.

Later when the code you write is running, R Studio will not include any line that is commented out in the calculations or procedures you are performing in your code.

Step 9. On line #3 in the R Script (we will be skipping line #2 for now), write the following comment to explain what your code will be about:

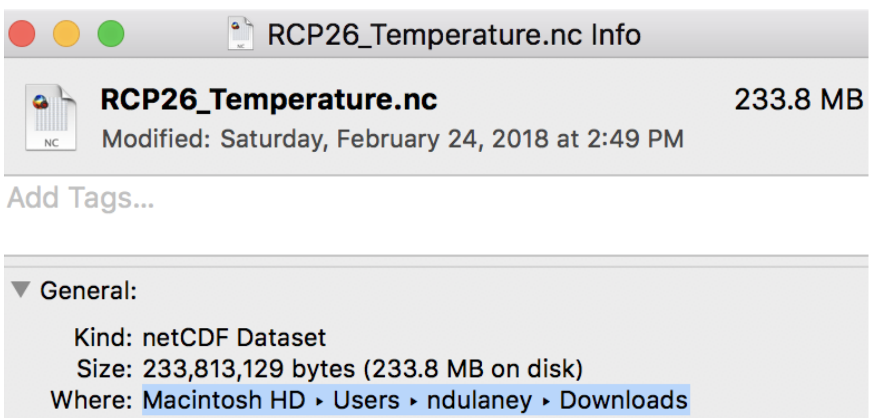
#This code will teach students how to load netCDF data into RStudio in order to create line plots of RCP temperature monthly average data.

Step 10. Next we need to learn how to load in the netCDF datasets we are interested in analyzing. The first dataset we will load in is the **RCP26_Temperature.nc** dataset we used in the previous lesson. This dataset provides monthly temperature at the surface projections from 2006 to 2100.

Before we can load the **RCP26_Temperature.nc** into RStudio, we need to know the file pathway. The file pathway describes the location of the file. For example, the file pathway for my **RCP26_Temperature.nc** file is **/Users/ndulaney/Downloads/RCP26_Temperature.nc**

This means the **RCP26_Temperature.nc** file is located in the Downloads folder under the ndulaney user.

If your computer is a Mac, to determine the file pathway, you need to right-click on the filename wherever the file is located and then click "**Get Info**". There will be a section named "**General**" and in that section next to the word "**Where**:" you will see the pathway. If you highlight that section after **"Where:"** is emphasized in the image below and copy and paste the contents into a blank Word document, the path name will be provided.



When I copy and paste the highlighted section as shown above, the result is **/Users/ndulaney/Downloads**

You will need to add **/RCP26_Temperature.nc** to the end of the file path in order to make the pathway complete. A complete file pathway is **/Users/ndulaney/Downloads/RCP26_Temperature.nc**
If your computer is a PC, to determine the file pathway, you need to right-click on the filename wherever the file is located and then click "**Properties**". Find where it says **"Location:"** and after location is the file pathway. Highlight the pathway and copy and paste it into a document. The result **could be** a pathway such as **C:\Users\ndulaney\Downloads**

You will need to add **\RCP26_Temperature.nc** to the end of the file path in order to make the pathway complete. A complete file pathway is **C:\Users\ndulaney\Downloads\RCP26_Temperature.nc**

***If you are using a PC, you will need to change all of the "\" to "/" after you obtain the file pathway.**

Q1. What is the complete file pathway for your **RCP26_Temperature.nc** file?

____

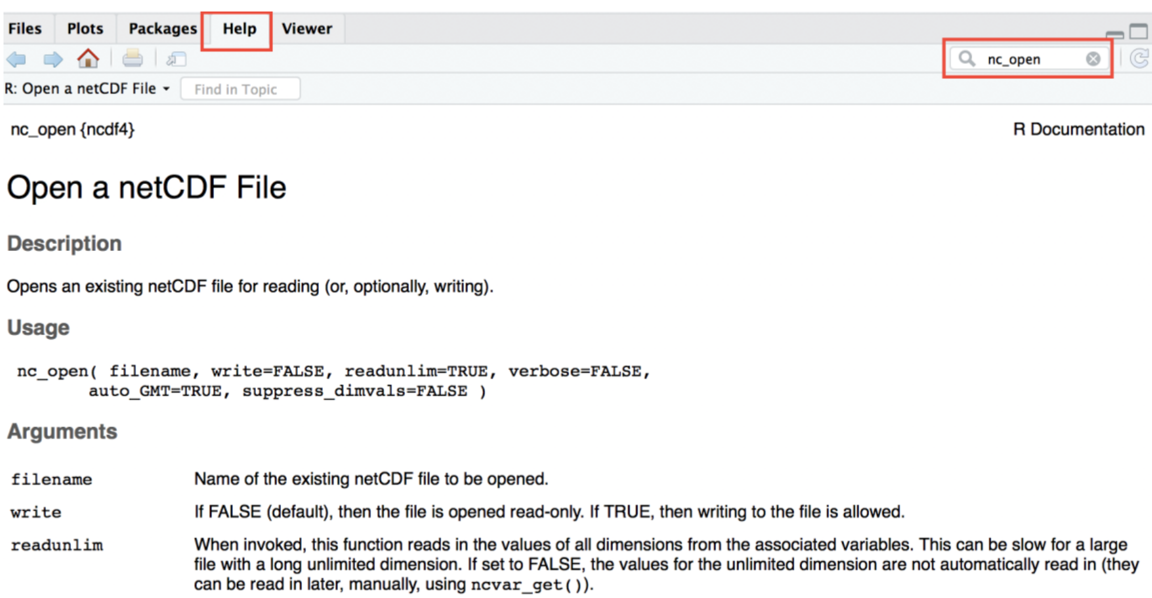
Step 11. Once you know the pathway of the **RCP26_Temperature.nc** file, you are ready to load the dataset into RStudio.

In line #4, write the following comment:

#We will now learn how to load a netCDF file into RStudio.

Step 12. When you load a dataset into RStudio, you need to set the dataset equal to an arbitrary name so you can refer to it later in the code. I am choosing to name the dataset **RCP26_Temp_Data**, **but feel free to name the dataset anything you wish.**

In order to load a netCDF file in R, we need to use the **nc_open** command. To learn more about the **nc_open** command, type **nc_open** in the search bar of the **Help** tab on the right side of RStudio, as shown in the image below.



nc_open {ncdf4} R Documentation

Open a netCDF File

Description

Opens an existing netCDF file for reading (or, optionally, writing).

Usage

```
nc_open( filename, write=FALSE, readunlim=TRUE, verbose=FALSE,
        auto_GMT=TRUE, suppress_dimvals=FALSE )
```

Arguments

filename	Name of the existing netCDF file to be opened.
write	If FALSE (default), then the file is opened read-only. If TRUE, then writing to the file is allowed.
readunlim	When invoked, this function reads in the values of all dimensions from the associated variables. This can be slow for a large file with a long unlimited dimension. If set to FALSE, the values for the unlimited dimension are not automatically read in (they can be read in later, manually, using ncvar_get()).

The **nc_open** command uses multiple arguments, but we will only be using the first argument named "**filename**". In this case, filename will be the file pathway we determined in step #10.

In line #5, type the name of the dataset you are choosing (as discussed in beginning of step #12) and set it equal to the **nc_open** command. An example of what to type is given below:

RCP26_Temp_Data <- nc_open("/Users/ndulaney/Downloads/RCP26_Temperature.nc")

RCP26_Temp_Data is the name of the dataset that will be loaded into RStudio, **nc_open** is the command used to open netCDF files, and **"/Users/ndulaney/Downloads/RCP26_Temperature.nc "** is the filename pathway for the **RCP26_Temperature.nc** file.

Note: Please be aware that you will need to change the file pathway to match the pathway that is specific for you. Your file pathway should NOT match the example given above!

Note: You need to keep your filename in quotations as shown in the example above.

Step 13. An example of my R Script is shown in the image below. Remember, your line #5 will look different due to your different file pathway and if you chose to name the loaded dataset something different from my example.

```
1  library(ncdf4)
2
3  #This code will teach students how to load netCDF data into RStudio in order to create line plots of RCP temperature
4  #We will now learn how to load a netCDF file into RStudio.
5  RCP26_Temp_Data <- nc_open("/Users/ndulaney/Downloads/RCP26_Temperature.nc")
```

Step 14. Highlight the first five lines of code and then click **Run** near the top right of the RScript**,** as shown in the image below.


```
1  library(ncdf4)
2
3  #This code will teach students how to load netCDF data into RStudio in order to create line plots of RCP temperature
4  #We will now learn how to load a netCDF file into RStudio.
5  RCP26_Temp_Data <- nc_open("/Users/ndulaney/Downloads/RCP26_Temperature.nc")
```

Check the **Console** to ensure there are no error messages. If there are no error messages, your **Console** will have no red error text. A correct Console is shown in the image below.

```
> library(ncdf4)
> #This code will teach students how to load netCDF data into RStudio in order to create line plots of RCP temperature
y average data.
> #We will now learn how to load a netCDF file into RStudio.
> RCP26_Temp_Data <- nc_open("/Users/ndulaney/Downloads/RCP26_Temperature.nc")
>
```

If there are error messages, they appear in red font. If there are error messages, it could be due to the fact that the ncdf4 library was not installed correctly, or the file pathway is wrong. It can also be helpful to copy and paste the error message into Google to learn more about your error.

Step 15. We now need to read in the dataset for the RCP 4.5 scenario. Use the information outlined in step #10 to determine the file pathway for the **RCP45_Temperature.nc** dataset.

On line #6, read in the RCP 4.5 temperature dataset. Be sure to name the dataset similar to how you named the RCP 2.6 temperature dataset. Below is a screenshot of my example code after reading in the RCP 4.5 dataset. ***<u>Remember, your code will not match exactly since your file pathways are different!</u>***

```
1 library(ncdf4)
2
3 #This code will teach students how to load netCDF data into RStudio in order to create line plots of RCP temperature
4 #We will now learn how to load a netCDF file into RStudio.
5 RCP26_Temp_Data <- nc_open("/Users/ndulaney/Downloads/RCP26_Temperature.nc")
6 RCP45_Temp_Data <- nc_open("/Users/ndulaney/Downloads/RCP45_Temperature.nc")
```

Step 16. Highlight the first six lines of code and then click **Run**. Check the **Console** to ensure there are no error messages.

Step 17. The RCP 2.6 and 4.5 datasets are now called **RCP26_Temp_Data** and **RCP45_Temp_Data**, respectively**.** We now need to extract the variable from the datasets that we want to explore. In order to determine the proper name of the variable in the dataset, we can use a command in RStudio called **names.**

We will use the **RCP26_Temp_Data** dataset as an example. In the **<u>Console</u>**, type **names(RCP26_Temp_Data$var)** and press enter. This will provide the name of the variable in the **RCP26_Temp_Data** dataset. The variable named **tas** should appear in the **Console** as shown in the image below:

```
> names(RCP26_Temp_Data$var)
[1] "tas"
```

Note: If you named the dataset something other than RCP26_Temp_Data, you will need to use that name instead of RCP26_Temp_Data when using the names command.

Step 18. We will now learn how to extract the **tas** variable from **RCP26_Temp_Data**. Type the following comment in line #8:

#We will now learn how to extract the tas variable from the dataset.

In order to extract a variable from a dataset, we need to use the command **ncvar_get.** To learn more about this command, go to the **Help** tab on the right ride of RStudio and in the search bar type **ncvar_get** and press enter.

In the **ncvar_get** command, the first argument is named **nc**, which is the name of the netCDF dataset we loaded in line #5 of the code. The first argument we will type in the **ncvar_get** command is **RCP26_Temp_Data.** The second argument for **ncvar_get** is called **varid**, which is the name of the variable we want to extract, which is **tas**. The variable name (varid) must be in quotations, such as **"tas".**

When you are extracting the **tas** variable with the **ncvar_get** command, you need to set the extracted variable equal to a name so you can refer to that name later. I will name the extracted variable **RCP26_Temp.**

In line #9 of the code, type **RCP26_Temp <- ncvar_get(RCP26_Temp_Data, "tas")**

***Remember that R is case sensitive! Uppercase and lowercase letters matter, and you need to pay special attention to this!**

Your R Script could now look similar to this image below:

```
1  library(ncdf4)
2  
3  #This code will teach students how to load netCDF data into RStudio in order to create line plots of RCP temperature
4  #We will now learn how to load a netCDF file into RStudio.
5  RCP26_Temp_Data <- nc_open("/Users/ndulaney/Downloads/RCP26_Temperature.nc")
6  RCP45_Temp_Data <- nc_open("/Users/ndulaney/Downloads/RCP45_Temperature.nc")
7  
8  #We will now learn how to extract the tas variable from the dataset.
9  RCP26_Temp <- ncvar_get(RCP26_Temp_Data, "tas")
```

Step 19. Highlight lines 8 and 9 and click **Run** to make sure these two lines of code are written correctly**.** Check the **Console** to ensure there are no error messages. If there is an error message, the most likely error is due to a typo in the **varid** argument of the **ncvar_get** command.

Step 20. We now need to extract the **tas** variable from the RCP 4.5 temperature dataset. Using the information outlined in step #18, use line #10 to extract the **tas** variable from the **RCP45_Temperature_Data** dataset.

Below is a screenshot image of my example code after extracting the **tas** variable from the **RCP45_Temperature_Data** dataset.

```
1  library(ncdf4)
2  
3  #This code will teach students how to load netCDF data into RStudio in order to create line plots of RCP temperature
4  #We will now learn how to load a netCDF file into RStudio.
5  RCP26_Temp_Data <- nc_open("/Users/ndulaney/Downloads/RCP26_Temperature.nc")
6  RCP45_Temp_Data <- nc_open("/Users/ndulaney/Downloads/RCP45_Temperature.nc")
7  
8  #We will now learn how to extract the tas variable from the dataset.
9  RCP26_Temp <- ncvar_get(RCP26_Temp_Data, "tas")
10 RCP45_Temp <- ncvar_get(RCP45_Temp_Data, "tas")
```

Step 21. Highlight line #10 and click **Run** to make sure the line of code is written correctly**.** Check the **Console** to ensure there are no error messages.

Step 22. We now need to figure out how many dimensions there are for the **tas** variable in each dataset. We will use the **RCP26_Temp** variable as an example. In the **Console**, type **dim(RCP26_Temp)** and press enter. Your **Console** should look like the following image below, with the dimensions 720, 278, 1140:

```
> dim(RCP26_Temp)
[1]  720  278 1140
```

The command **dim** provides the number of dimensions and the amount in each dimension**.** The result of **dim(RCP26_Temp)** is **720 278 1140**. This means there are three dimensions in the dataset.

- The first dimension represented by 720 is longitude, which means there are 720 longitude values in **RCP26_Temp.**
- The second dimension represented by 278 is latitude, which means there are 278 latitude values in **RCP26_Temp.**
- The third dimension represented by 1140 is time, which means there are 1140 time values in **RCP26_Temp.**

The **tas** variable from **RCP45_Temp** has the same dimension.

Note: *Due to the arrangement of netCDF data, longitude is first, latitude is second, and time is third.*

Step 23. Data in the form of netCDF (which is the format for most climate-related datasets) is structured in terms of grid boxes. For example, for the **RCP26_Temp** variable, there are 720 longitude grid boxes and 278 latitude grid boxes that span the surface of the Earth.

Each grid box is assigned a value from **RCP26_Temp** which corresponds to a specific latitude and longitude value measured in degrees. The following will help explain how grid box values correspond to specific latitude and longitude values.

Longitude: There are 720 longitude grid boxes in variable **RCP26_Temp**. In reality, there are 180 east longitudes and 180 west longitudes, which corresponds to a total 360 degrees of longitude on Earth. This means that each grid box in **RCP26_Temp** consists of data representing 0.5 degrees of longitude. In this dataset, longitude values start at a value of 0.5 degrees east and increase by a value of 0.5 degrees for each grid box. The change of value of 0.5˚ is also known as the resolution of the dataset. For an example, longitude grid box #1 represents a **RCP26_Temp** value at 0.5 degrees east longitude, grid box #2 represents a **RCP26_Temp** value at 0.75 degrees east longitude, grid box #3 represents a value at 1.25 degrees east longitude, etc.

Latitude: There are 278 latitude grid boxes in variable **RCP26_Temp**. In reality, there are 90 north latitudes and 90 south latitudes, which corresponds to a total of 180 degrees of latitude on Earth. Each grid box in **RCP26_Temp** consists of model output representing 0.5 degrees of latitude between each grid box (the resolution for latitude is also 0.5˚). In this dataset, latitude values start at a value of -55.25 degrees north (which is equivalent to 55.25 degrees south) and end at a value of 83.25 degrees north. Latitude values increase by a value of 0.5 degrees for each grid box. For example, latitude grid box #1 represents a **RCP26_Temp** value of -55.25 degrees north (55.25˚S) latitude, grid box #2 represents a **RCP26_Temp** value at -54.75 degrees north (54.75˚S) latitude, grid box #3 represents a value at -54.25 degrees north (54.25˚S) latitude, etc.

Step 24. There are 1,140 time components of the **RCP26_Temp** variable. Time component #1 corresponds to **RCP26_Temp** output from January 2006, time component #2 corresponds to **RCP26_Temp** output from

February 2006, time component #3 corresponds to **RCP26_Temp** output from March 2006, etc. The last time component 1,140 corresponds to December 2100.

Q2. Why are there 1,140 time components in these datasets?

____

Step 25. On line #12 of your code, write the following comment:

#Create a data subset for just New York City Coordinates (40.7˚N, 74˚W)

In order to make a data subset of the **RCP26_Temp** variable, we need to specify a name for the data subset. I am choosing to name the data subset **RCP26_Temp_NYC.** We now need to set the **RCP26_Temp_NYC** data subset equal to the **RCP26_Temp** variable with the proper grid boxes for New York City.

To specify the proper grid box values for New York City based on its latitude and longitude, two functions were created in an RScript titled **Functions.R**. One function allows users to input a longitude value, and the result of the function is the proper grid box number for a specific longitude value. The other function allows users to input a latitude value to determine the proper grid box number for a specific latitude. The purposes of using these functions are to save the students time and to ensure students are finding the correct grid box numbers.

The name of the function created in **Functions.R** that determines the latitude grid box number is **LatGrid** and the name of the function that determines the longitude grid box for east longitudes is **LonGrid_East** and the function for west longitudes is **LonGrid_West**. **Due to the nature of the longitude values, there needs to be two separate functions for west and east longitudes.** For these functions to work, a user needs to source the file that contains the functions, which is **Functions.R.** The file should be sourced in the beginning of the code. The file pathway of **Functions.R** is needed in order to source the file. If you need help determining the file pathway of **Functions.R**, please refer to step #10 of this activity.

The following is an example of how to source the **Functions.R** file. ***Please note that the example includes a file pathway that is different from your file pathway!***

Go to line #2 of your Rscript and type a line of code similar to the following (the file pathway will be different):

source("/Users/ndulaney/Documents/Functions.r")

Here, the function **source** is telling RStudio to source the file **Functions.R** located at the pathway provided. Once **Functions.R** is sourced, all of the functions within **Functions.R** can be used in your current RScript.

Step 26. Highlight and run line #2 of your RScript so that RStudio knows the functions created in **Functions.R.**

Now that RStudio knows the functions **LatGrid** and **LonGrid_East, and LonGrid_West**, we can learn how the functions work.

Go to the **Console** and type **LatGrid(52)** and then press enter. The result should look like the image below.

```
> LatGrid(52)
[1] "Gridpoint 216 is ~ Latitude 52.25 degrees North; bounded by 51.75 degrees North and 52.25 degrees North"
[1] 216
```

This means that for a latitude of 52˚N, the assigned latitude grid box value is 216.

Q3. Using the **Console** and the function **LatGrid**, determine the latitude grid box values for the following latitude values (remember, south latitude values are represented by negative numbers):

Latitude = 68˚N **Grid Box #** = ___________

Latitude = 25˚S **Grid Box** # = ___________

Latitude = 14˚N **Grid Box #** = ___________

Q4. Using the **Console** and the function **LonGrid_East or LonGrid_West**, determine the longitude grid box values for the following longitude measurements (remember, west longitude values are represented by negative numbers and should be put as negative numbers into the function, such as LonGrid_West(-38) for 38˚W longitude):

Longitude = 116˚E **Grid Box #** = ___________

Longitude = 35˚W **Grid Box** # = ___________

Longitude = 77˚W **Grid Box** # = ___________

Step 27. Now that we know how the functions **LatGrid**, **LonGrid_East**, and **LonGrid_West** work, we are ready to use them to create the data subset for NYC.

On line #13 of your code, write the following:

RCP26_Temp_NYC <- RCP26_Temp[LonGrid_West(-74.0),LatGrid(40.7),]

Here, **RCP26_Temp_NYC** is set equal to **RCP26_Temp** only at the grid box for the ***west longitude*** specified by LonGrid_West(-74.0), the grid box for latitude specified by LatGrid(40.7), at all time slices (all months from January 2006 to December 2100). In RStudio, leaving a dimension blank tells the program to include all components from that specific dimension. ***Note:*** *Due to the arrangement of netCDF data, longitude is first, latitude is second, and time is third.*

Below is a screenshot of what your code for lines #12 and #13 could look like.

```
12 #Create a data subset for just New York City Coordinates (40.7˚N, 74˚W)
13 RCP26_Temp_NYC <- RCP26_Temp[LonGrid_West(-74.0),LatGrid(40.7), ]
```

Step 28. Run lines #12 & #13 of your code to make sure there are no error statements in the Console. If there are error statements, it could be due to a spelling error or a capitalization error. You can also type the error statement into Google if you are unsure how to progress.

Step 29. We now need to create data subsets for New York City from the RCP 4.5 dataset. Using the information outlined in step #29, use line #14 of your code to create a data subset for New York City from the **RCP45_Temp** variable.

Below is a screenshot of my example code after creating data subsets for New York City for the **RCP45_Temp** variable.

```
12 #Create a data subset for just New York City Coordinates (40.7˚N, 74˚W)
13 RCP26_Temp_NYC <- RCP26_Temp[LonGrid_West(-74.0),LatGrid(40.7), ]
14 RCP45_Temp_NYC <- RCP45_Temp[LonGrid_West(-74.0),LatGrid(40.7), ]
```

Step 30. Run line #14 to make sure there are no error statements in the Console.

Step 31. By creating a data subset for a specific location for all time slices, such as **RCP26_Temp_NYC**, you are specifying one RCP 2.6 temperature value at each time slice. Since there are 1,140 time slices in the dataset, **RCP26_Temp_NYC** should contain exactly 1,140 values.

To verify this, we can use a command in R called **length**. Go to the **<u>Console</u>**, type **length(RCP26_Temp_NYC)**, and press enter to find out the length of **RCP26_Temp_NYC.** This process in the Console is illustrated in the image below.

```
> length(RCP26_Temp_NYC)
[1] 1140
```

The length should also be the same for the **RCP45_Temp_NYC** subset.

Step 32. Similar to the analysis we conducted in Lessons #1 of this unit, we are interested in how the RCP 4.5 temperature projections compare to the RCP 2.6 temperature projections. In order to make a comparison, we need to subtract the RCP 2.6 temperature projection model output from the RCP 4.5 scenario.

On line #16 of the code, write the following commented statement:

#Calculate the projections from RCP 4.5 - 2.6

Similar to the other tasks we performed in our code thus far, we need to name the data that results from the subtraction of RCP 4.5 & RCP 2.6. I am choosing to name the resulting data from subtracting RCP 4.5 and RCP 2.6 **RCP45_RCP26_Temp_NYC.**

On line #17 of your code type the following:
RCP45_RCP26_Temp_NYC <- RCP45_Temp_NYC - RCP26_Temp_NYC

This line takes the **RCP26_Temp_NYC** data created in line #13 of the code and subtracts it from **RCP45_Temp_NYC** data created in line #14 of the code. The result is **RCP45_RCP26_Temp_NYC**

The length of **RCP45_RCP26_Temp_NYC** should be equal to 1,140.

Step 33. Highlight and run lines #16 and #17 and ensure there are no error statements in the Console.

Step 34. We are now going to create three different 30-year subsets of the **RCP45_RCP26_Temp_NYC** future projection data. The goal of creating three different 30-year subsets of **RCP45_RCP26_Temp_NYC** is to analyze the differences in the RCP 4.5 and RCP 2.6 temperature projections at different intervals in the future. Temperature will be changing gradually over the next century and using different intervals allows scientists to get a better idea of when changes will be most drastic. Scientists use 30-year averages when analyzing changes in climate because statistically, 30 values are needed to accurately calculate an average. Using less than 30 years can result in an unreliable average, while using more than 30 years can skew results.

Q5. Why do scientists use 30 years of data when analyzing temperature changes?

____

Step 35. The model output in **RCP26_Temperature.nc**, **RCP45_Temperature.nc,** and all of the other datasets we downloaded in the beginning of this activity contains output from January 2006 to December 2100. In order to create 30-year data intervals that end with December 2100, we need to start our first 30-year interval at January 2011. Each time component, such as January 2011, corresponds to a specific time grid box number. The **Functions.R** file used earlier also contains a function to determine the time grid box number that corresponds to a specific month and year. The function is **MonYearGrid** and allows users to input a specific month and year, such as **"Jan 2011"**, and the result is the time grid box number.

To use the **MonYearGrid** function, users need to have the **zoo** package installed. To install the **zoo** package, got to the **Console** and **type** the following and press enter:

install.packages("zoo")

Once the zoo package is installed, we can now learn how the function **MonYearGrid** works. Go to the **Console** and type the following and press enter:

MonYearGrid("Jan 2011")

The result should be time grid box 61. This means that the grid box number for January 2011 is 61. This process is illustrated below.

```
> MonYearGrid("Jan 2011")
[1] 61
```

Note: To properly use the function MonYearGrid, the month & year must be in quotations as shown above, and each month must be abbreviated to its first three letters.

Step 36. We now need to determine the time grid box numbers for the start and end of each 30-year interval. The time grid box number for January 2011 has already been determined for you. Complete the following questions by using the Console and the function **MonYearGrid**. Remember, the month & year must be in quotations and the month names need to be abbreviated to their first three letters.

Q6. 30-year Interval #1: January 2011 to December 2040
January 2011 time grid box #: **61**
December 2040 time grid box #: _______

Q7. 30-year Interval #2: January 2041 to December 2070
January 2041 time grid box #: _______
December 2070 time grid box #: _______

Q8. 30-year Interval #3: January 2071 to December 2100
January 2071 time grid box #: _______
December 2100 time grid box #: _______

Step 37. Now that we know the time grid box numbers that start and end each 30-year interval, we can create the 30-year subsets in RStudio. Go to line #19 of the code and type the following comment:

#Create 30-year subsets from 2011 to 2100

Go to line #20 of the code and type the following comment:

#First 30-year subset will be January 2011 to December 2040

In order to create the first 30-year subset from January 2011 to December 2040, we need to extract the temperature values between January 2011 and December 2040. **RCP45_RCP26_Temp_NYC** contains the difference in temperature values between the RCP 4.5 & RCP 2.6 scenarios from January 2006 (time grid box #1) to December 2100 (time grid box #1140). Since we know the time grid box numbers for the beginning and end of the first interval, we can create the subset by specifying values from grid box #61 (Jan 2011) to grid box #420 (Dec 2040). This can be done with the following statement: **RCP45_RCP26_Temp_NYC[61:420]**

Putting brackets after **RCP45_RCP26_Temp_NYC** tells RStudio that you are going to create a subset of that overall dataset. The numbers in the brackets, **61:420**, for instance, tells RStudio that you are making the subset from the 61st value to the 420th value. The colon (:) in between the numbers tells RStudio to include all numbers from 61 to 420.
Similar to the previous steps, we need to name the subset. We will choose to name the subset **RCP45_RCP26_Temp_NYC_1.** The "1" at the end of the name signifies the first 30-year interval.

Step 38. Go to line #21 of the code and type the following:
RCP45_RCP26_Temp_NYC_1 <- RCP45_RCP26_Temp_NYC[61:420]

Now, **RCP45_RCP26_Temp_NYC_1** contains the first 30-year subset from January 2011 to December 2040.

Step 39. Use lines #23 to #27 to write comments and create the second and third 30-year subsets. The second 30-year subset is from January 2041 to December 2070, and the third 30-year subset is from January 2071 to December 2100. Use the answers **to Q6 to Q8** in step #36 of this activity for help, if needed.

Step 40. After successful completion of step #39, your code could look like the following image:

```
19 #Create 30-year subsets from 2011 to 2100
20 #First 30-year subset will be January 2011 to December 2040
21 RCP45_RCP26_Temp_NYC_1 <- RCP45_RCP26_Temp_NYC[61:420]
22
23 #Second 30-year subset will be January 2041 to December 2070
24 RCP45_RCP26_Temp_NYC_2 <- RCP45_RCP26_Temp_NYC[421:780]
25
26 #Third 30-year subset will be January 2071 to December 2100
27 RCP45_RCP26_Temp_NYC_3 <- RCP45_RCP26_Temp_NYC[781:1140]
```

Step 41. Highlight and run lines #19 to #27 to ensure there are no error messages in the Console. If there are error messages, it is most likely due to a spelling or capitalization error. You can also copy & paste your error message into Google to learn more about your error.

Step 42. Each 30-year subset contains 360 months of data (12 months x 30 years) and therefore 360 data values, one value for each month. To verify this, go to the **Console** and use the length command to verify the length of each 30-year subset.

In this activity, we are interested in evaluating monthly averages for each of the three 30-year subsets. For example, for each 30-year subset, we want to calculate the average value of each month, so we have one value to represent the January average of that subset, another value to represent the February average of that subset, and so-on. In order to do this, we need to specify which values in each 30-year subset represent January values, February values, March values, and so-on.

A function was created in the file **Functions.R** that assigns all time grid box values to a specific month. The function is called **Months_Data.** For example, each 30-year subset contains 360 months of data. The 1st, 13th, 25th, etc. time values all correspond to the month of January. The function **Months_Data** takes all of the January time values and groups them together, as well as the time values for all months of the year.
To see how this function works, go to the Console and **type** the following and press enter:

Months_Data(1)

Here, **Months_Data** is the function and **1** represents the month of January. All other months can be identified by their corresponding number as well (February = 2, March = 3 ,…, December =12). The result is a list of all of the time grid box numbers that correspond to January months. A screen shot of this process is provided in the image below.

```
> Months_Data(1)
 [1]   1  13  25  37  49  61  73  85  97 109 121 133 145 157 169 181 193 205 217 229 241 253 265 277 289 301 313 325
[29] 337 349
```

Step 43. Now that we know how to use the function **Months_Data**, we need to use the function in our code to calculate monthly averages for each month in the 30-year subsets. Our goal is to find the average January value, the average February value, etc. in each of the three 30-year intervals so we can determine which 30-year interval will result in the biggest differences between the RCP 4.5 and RCP 2.6 scenarios during each month. We will start by calculating monthly averages for the first 30-year interval representing January 2011 to December 2040.

Go to line #29 of the code and type the following commented statement:

#Calculate the monthly average for each month from January 2011 to December 2040

We will first start with the January monthly average. To calculate an average, we need to use the **mean** command. To learn more about the **mean** command, type **mean** in the search bar of the **Help** tab on the right side of RStudio.

We are only interested in using the first argument of the **mean** command, which is the name of the dataset you are calculating the mean of. In our case, we are calculating the mean of **RCP45_RCP26_Temp_NYC_1**. However, since we are interested in calculating an average of just the January values from **RCP45_RCP26_Temp_NYC_1**, we need to specify that we are averaging only the January values from **RCP45_RCP26_Temp_NYC_1.** To do this, we can use the following:
RCP45_RCP26_Temp_NYC_1[Months_Data(1)]

Putting **Months_Data(1)** in brackets after **RCP45_RCP26_Temp_NYC_1** tells RStudio to only average the January values determined through the function **Months_Data**.

Similar to all other lines of code thus far, we need to name the result of finding the mean of all of the January values from **RCP45_RCP26_Temp_NYC_1**. We can name the result **Jan_Avg_1** (the "1" signifies the first 30-year time interval).

Step 44. Go to line #30 of the code and type the following statement:

Jan_Avg_1 <- mean(RCP45_RCP26_Temp_NYC_1[Months_Data(1)])

Here we are calculating the mean of all of the January values from **RCP45_RCP26_Temp_NYC_1** and setting it equal to **Jan_Avg_1**.

Step 45. Using lines #31 through #41, write lines of code that calculate the mean of the first 30-year interval of the RCP 4.5 – RCP 2.6 scenario, **RCP45_RCP26_Temp_NYC_1,** for February through December.

Highlight and run lines #29 to #41 and check the Console to ensure there are no errors.

Once you calculate the mean for January through December by writing code on lines #29 through #41, your code could look like the following:

```
29 #Calculate the monthly average for each month from January 2011 to December 2040
30 Jan_Avg_1 <- mean(RCP45_RCP26_Temp_NYC_1[Months_Data(1)])
31 Feb_Avg_1 <- mean(RCP45_RCP26_Temp_NYC_1[Months_Data(2)])
32 Mar_Avg_1 <- mean(RCP45_RCP26_Temp_NYC_1[Months_Data(3)])
33 Apr_Avg_1 <- mean(RCP45_RCP26_Temp_NYC_1[Months_Data(4)])
34 May_Avg_1 <- mean(RCP45_RCP26_Temp_NYC_1[Months_Data(5)])
35 Jun_Avg_1 <- mean(RCP45_RCP26_Temp_NYC_1[Months_Data(6)])
36 Jul_Avg_1 <- mean(RCP45_RCP26_Temp_NYC_1[Months_Data(7)])
37 Aug_Avg_1 <- mean(RCP45_RCP26_Temp_NYC_1[Months_Data(8)])
38 Sep_Avg_1 <- mean(RCP45_RCP26_Temp_NYC_1[Months_Data(9)])
39 Oct_Avg_1 <- mean(RCP45_RCP26_Temp_NYC_1[Months_Data(10)])
40 Nov_Avg_1 <- mean(RCP45_RCP26_Temp_NYC_1[Months_Data(11)])
41 Dec_Avg_1 <- mean(RCP45_RCP26_Temp_NYC_1[Months_Data(12)])
```

Step 46. Go to the **Console** and type **Jan_Avg_1** and press enter to see the mean value of all of Januarys from the first 30-year interval of RCP 4.5 – RCP 2.6.

The value of **Jan_Avg_1** should be **0.6198556˚C**. **Jan_Avg_1** was calculated by first subtracting the RCP 4.5 and RCP 2.6 scenarios and then taking the mean of all of the January values from RCP 4.5 – RCP 2.6 between January 2011 and December 2040. As a result, **Jan_Avg_1** value of **0.6198556˚C** is not the actual average January temperature, rather it is a comparison of RCP 4.5 to RCP 2.6.

For example, **Jan_Avg_1** is **0.6198556˚C,** a positive value, which means that the RCP 4.5 scenario is **0.6198556˚C** greater than the RCP 2.6 scenario for the January average of the first 30-year interval. In short, the RCP 4.5 scenario has warmer temperatures than the RCP 2.6 scenario during the month of January for the first 30-year interval.

Q9. What does a positive value of RCP 4.5 – RCP 2.6 indicate?

____

Q10. What does a negative value of RCP 4.5 – RCP 2.6 indicate?

____

Q11. Use the **Console** to analyze the values of all monthly averages of RCP 4.5 – RCP 2.6 during the first 30-year interval.

List the names of all of the months where the average monthly temperature of the RCP 4.5 scenario was ***greater than*** the RCP 2.6 scenario for the first 30-year interval (2011 – 2040).

____

List the names of all of the months where the average monthly temperature of the RCP 4.5 scenario was ***less than*** the RCP 2.6 scenario for the first 30-year interval (2011 – 2040).

____

Step 47. Now that we calculated the monthly averages for the first 30-year interval for the RCP 4.5 – RCP 2.6 scenario, we need to put all of the monthly averages into one dataset so we can later put this data on a line graph in RStudio.

To create a dataset in RStudio, we can use a command called **c**, which stands for combine. To learn more about the **c** command, go to the **Help** tab located on the bottom right panel of RStudio and type **c**.

The **c** command works by combining all arguments put into the command and making one list of data. Each argument must be separated by a comma inside a set of parentheses following the **c** command.

Since we want to put all of the monthly averages from the first 30-year interval into one list of data, we need to combine **Jan_Avg_1**, **Feb_Avg_1**, **Mar_Avg_1**, etc.

Step 48. Go to line #43 of your code and type the following commented statement:

#Create a vector that contains the monthly averages from January 2011 to December 2040. The length of the vector will be 12, one monthly average value for each month of the year

To create the vector (list of data), go to line #44 of the code and type the following (It should all be written on one line in the script; the text is broken up below due to space):

Monthly_Average_1 <- c(Jan_Avg_1,Feb_Avg_1,Mar_Avg_1,Apr_Avg_1,May_Avg_1,Jun_Avg_1,Jul_Avg_1,Aug_Avg_1,Sep_Avg_1,Oct_Avg_1,Nov_Avg_1,Dec_Avg_1)

Here, **Monthly_Average_1** represents the combined list of all of the monthly averages for RCP 4.5 – RCP 2.6 for the first 30-year interval. The data in **Monthly_Average_1** will be used later to create a line graph representing the monthly averages for the first 30-year interval.

Step 49. Highlight and run lines #43 and #44 and check the Console to ensure there are no error statements.

Step 50. Now we need to calculate monthly averages for the second and third 30-year intervals representing years 2041 – 2070 and 2071 – 2100, respectively.

Use line #46 to write the following commented statement:

#Calculate the monthly average for each month from January 2041 to December 2070

Beginning at line #47 and ending at line #58, write lines of code that calculate the average monthly temperature of RCP 4.5 – RCP 2.6 for the second 30-year interval. If you go back to line #24 of your code, you will see that we named the result of subtracting RCP 4.5 – RCP 2.6 of the second 30-year interval **RCP45_RCP26_Temp_NYC_2**. You will need to use **RCP45_RCP26_Temp_NYC_2** to calculate the monthly mean values.

An example of what to type on line #47 of your code is provided below. You will be responsible for writing the lines of code for all of the remaining months.

Jan_Avg_2 <- mean(RCP45_RCP26_Temp_NYC_2[Months_Data(1)])

Step 51. Highlight and run lines #46 to #58 and check the Console to ensure there are no errors.

Step 52. Use lines #60 and #61 to write a commented statement and to create a data list (vector) titled **Monthly_Average_2** consisting of the 12 monthly averages calculated in lines #47 to #58 using the **c** command. Look back to step #48 of this activity, if needed.

Highlight and run lines #60 and #61 to ensure there are no error statements.

Step 53. Use lines #63 to #75 to write a commented statement and to calculate the monthly averages for the third 30-year interval (2071 – 2100). Highlight and run lines #63 to #75 when you are finished to ensure there are no errors.

Step 54. Use lines #77 and #78 to write a commented statement and to create a data list (vector) titled **Monthly_Average_3** consisting of the 12 monthly averages calculated in lines #64 to #75 using the **c** command. Look back to step #48 of this activity, if needed.

Step 55. Now that we have calculated monthly averages for each 30-year subset for the RCP 4.5 – RCP 2.6 scenario, we need to analyze the calculations to ensure understanding of what the numbers mean.

Q12. Use the **Console** to analyze the values of all monthly averages of RCP 4.5 – RCP 2.6 during the **<u>second 30-year interval (2041 – 2070)</u>**.

List the names of all of the months where the average monthly temperature of the RCP 4.5 scenario was ***greater than*** the RCP 2.6 scenario for the second 30-year interval (2041 – 2070).

____

List the names of all of the months where the average monthly temperature of the RCP 4.5 scenario was ***less than*** the RCP 2.6 scenario for the second 30-year interval (2041 – 2070).

____

Q13. Use the **Console** to analyze the values of all monthly averages of RCP 4.5 – RCP 2.6 during the **<u>third 30-year interval (2071 – 2100)</u>**.

List the names of all of the months where the average monthly temperature of the RCP 4.5 scenario was ***greater than*** the RCP 2.6 scenario for the third 30-year interval (2071 – 2100).

____

List the names of all of the months where the average monthly temperature of the RCP 4.5 scenario was ***less than*** the RCP 2.6 scenario for the third 30-year interval (2071 – 2100).

____

Step 56. Use the **Console** to determine which 30-year subset results in the greatest difference between the RCP 4.5 and RCP 2.6 scenario. Here, it does not matter whether the value is positive or negative. We are interested in the greatest difference, whether it is positive or negative.

An example on how to do this is provided in the screenshot below for the month of January.

```
> Jan_Avg_1
[1] 0.6198556
> Jan_Avg_2
[1] 1.001201
> Jan_Avg_3
[1] 2.835113
```

Meaning:
The third 30-year interval representing 2071 – 2100 has a higher difference in temperature from the RCP 4.5 - RCP 2.6 scenario in the month of January than the two other 30-year intervals. Also, as time increases, the difference in temperature during the month of January from the RCP 4.5 – RCP 2.6 scenario also increases. This means that the disparity in temperature between the RCP 4.5 and RCP 2.6 scenarios increases with time.

Q14. Use the Console to conduct a similar analysis to the one in step #56 for all of the months. January has been done for you as an example.

January: Which 30-year interval has the greatest difference in temperature between the RCP 4.5 – RCP 2.6 scenario? Please provide the years of the 30-year interval.

2071 – 2100

February: Which 30-year interval has the greatest difference in temperature between the RCP 4.5 – RCP 2.6 scenario? Please provide the years of the 30-year interval.

____

March: Which 30-year interval has the greatest difference in temperature between the RCP 4.5 – RCP 2.6 scenario? Please provide the years of the 30-year interval.

____

April: Which 30-year interval has the greatest difference in temperature between the RCP 4.5 – RCP 2.6 scenario? Please provide the years of the 30-year interval.

____

May: Which 30-year interval has the greatest difference in temperature between the RCP 4.5 – RCP 2.6 scenario? Please provide the years of the 30-year interval.

____

June: Which 30-year interval has the greatest difference in temperature between the RCP 4.5 – RCP 2.6 scenario? Please provide the years of the 30-year interval.

____

July: Which 30-year interval has the greatest difference in temperature between the RCP 4.5 – RCP 2.6 scenario? Please provide the years of the 30-year interval.

____

August: Which 30-year interval has the greatest difference in temperature between the RCP 4.5 – RCP 2.6 scenario? Please provide the years of the 30-year interval.

____

September: Which 30-year interval has the greatest difference in temperature between the RCP 4.5 – RCP 2.6 scenario? Please provide the years of the 30-year interval.

____

October: Which 30-year interval has the greatest difference in temperature between the RCP 4.5 – RCP 2.6 scenario? Please provide the years of the 30-year interval.

____

November: Which 30-year interval has the greatest difference in temperature between the RCP 4.5 – RCP 2.6 scenario? Please provide the years of the 30-year interval.

____

December: Which 30-year interval has the greatest difference in temperature between the RCP 4.5 – RCP 2.6 scenario? Please provide the years of the 30-year interval.

____

Q15. Based on your answers to Q14, what general conclusion can we make about the 30-year intervals and the difference in temperature between the RCP 4.5 and RCP 2.6 scenario?

____

Step 57. We will now learn how to make a line plot in RStudio that contains three lines, one for each 30-year interval. To do this, we will use the **plot** command. To learn more about the **plot** command, type **plot** in the search bar of the **Help** tab on the right side of RStudio and choose **Generic X-Y Plotting**, as shown in the image below.

plot {graphics} R Documentation

Generic X-Y Plotting

Description

Generic function for plotting of R objects. For more details about the graphical parameter arguments, see `par`.

For simple scatter plots, `plot.default` will be used. However, there are `plot` methods for many R objects, including `function`s, `data.frame`s, `density` objects, etc. Use `methods(plot)` and the documentation for these.

Usage

```
plot(x, y, ...)
```

Arguments

`x`	the coordinates of points in the plot. Alternatively, a single plotting structure, function or *any R object with a `plot` method* can be provided.
`y`	the y coordinates of points in the plot, *optional* if `x` is an appropriate structure.
`...`	Arguments to be passed to methods, such as graphical parameters (see `par`). Many methods will accept the following arguments:

The first argument of the **plot** command is the x variable. We will start with the first 30-year interval data titled **Monthly_Average_1.** Since the **Monthly_Average_1** data we want to plot has one temperature value for each month, we only need to specify **Monthly_Average_1** in the **plot** command. We do not need to specify any y-coordinates at this time.

The second argument we need to specify is the type of plot we want to create. When using the **Help** tab to learn more about the **plot** command, you can scroll down under the **Generic X-Y Plotting** section to learn about different plot types, as shown in the image below.

`type`
what type of plot should be drawn. Possible types are

- `"p"` for **p**oints,
- `"l"` for **l**ines,
- `"b"` for **b**oth,
- `"c"` for the lines part alone of `"b"`,
- `"o"` for both '**o**verplotted',
- `"h"` for '**h**istogram' like (or 'high-density') vertical lines,
- `"s"` for stair **s**teps,
- `"S"` for other **s**teps, see 'Details' below,
- `"n"` for no plotting.

We are interested in creating a line graph and will therefore use the plot type "l".

After the second argument, the user can include a variety of additional arguments. Below contains a list of arguments we could use with our **plot** command.

- **x = Monthly_Average_1**
- **type** = "l" (This specifies that the type of plot will be "l", a line graph. The "l" must be in quotations.)
- **col** = "blue" (This specifies that the color of the line graph will be blue. This can be interchanged to any color found here: [Color names for use in R](). Please note the name of the color must be in quotations.)
- **xlab** = "Months" (This specifies the label on the x-axis and must be in quotations.)
- **ylab** = "RCP 4.5 - 2.6 Temperature (˚C)" (This specifies the label on the y-axis and must be in quotations.)

Step 58. There is one more argument we need to include, **ylim**. The argument **ylim** sets the limits of the numbers on the y-axis. Since we will be plotting three different lines, one for each 30-year interval, we need to ensure the y-axis values account for the greatest and least temperature values. To do this, we can use a command in RStudio called **max** that finds the maximum value out of all three monthly average datasets. Once we find this maximum value, we can have **ylim** ensure the axis accounts for the maximum value, and the negated value of the maximum value. We need to account for the negated value because the y-axis needs to be centered around zero.

For example, if the maximum value is 5, in order to center the y-axis around zero, we need to ensure the y-axis goes from -5 to 5.

Go to line #80 and write the following commented statement:

#Find the maximum absolute value of all monthly average values to help set the y-axis limits when plotting

To use the **max** command, go to line #81 and type the following:

Max_Abs_Value <- max(c(Monthly_Average_1,Monthly_Average_2,Monthly_Average_3))

Here, **Max_Abs_Value** is what we are naming the maximum data value out of all of the data. The **max** command is finding the maximum value out of Monthly_Average_1, Monthly_Average_2, and Monthly_Average_3 and setting it equal to **Max_Abs_Value.**

Step 59. Now that we know how to find the maximum data value, we can now go back to creating the plot. Go to line #83 of the code and type the following commented statement:

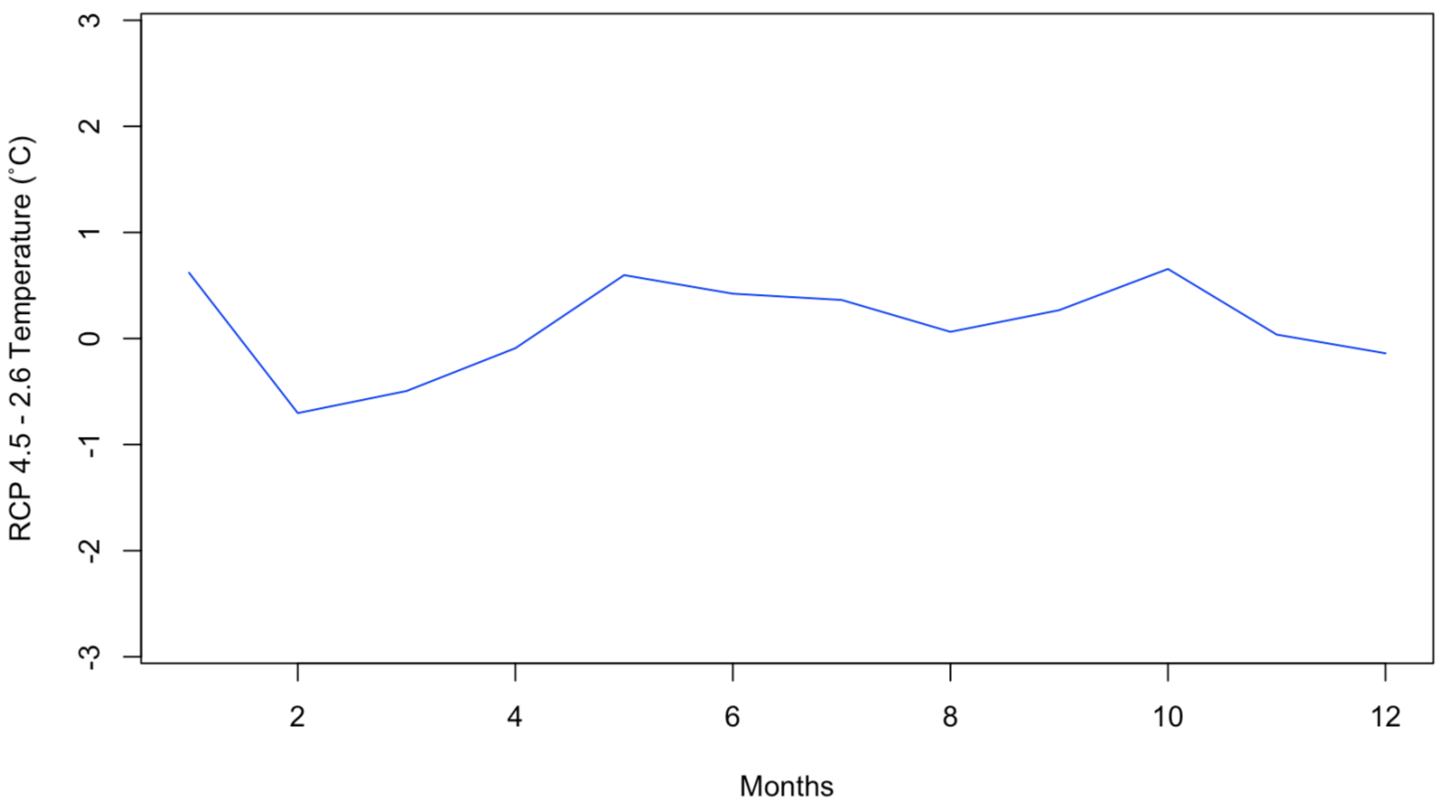
#Create a triple-line graph to show the differences in the seasonal cycle for the different 30-year averages

Go to line #84 of the code and type the following:

plot(Monthly_Average_1, type="l", col="blue", xlab="Months", ylab="RCP 4.5 - 2.6 Temperature (˚C)", ylim=c(-Max_Abs_Value,Max_Abs_Value))

All of the arguments in the plot command listed above were explained in step #57 of the activity, except for **ylim**. Here, **ylim=c(-Max_Abs_Value,Max_Abs_Value)** means the lowest number on the y-axis is set to the negated maximum data value, while the highest number on the y-axis is set to the maximum data value.

Step 60. Highlight and run lines #80 to #84. If there are no errors in the Console, you should now see a plot appear on the bottom right window of RStudio, as shown below.



Step 61. The plot you just created has the months on the x-axis counting by 2's. This was done automatically by RStudio but can be changed by using a command called **axis**. To learn more about the **axis** command, go to the **Help** tab near the bottom right of RStudio and type in "**axis**".

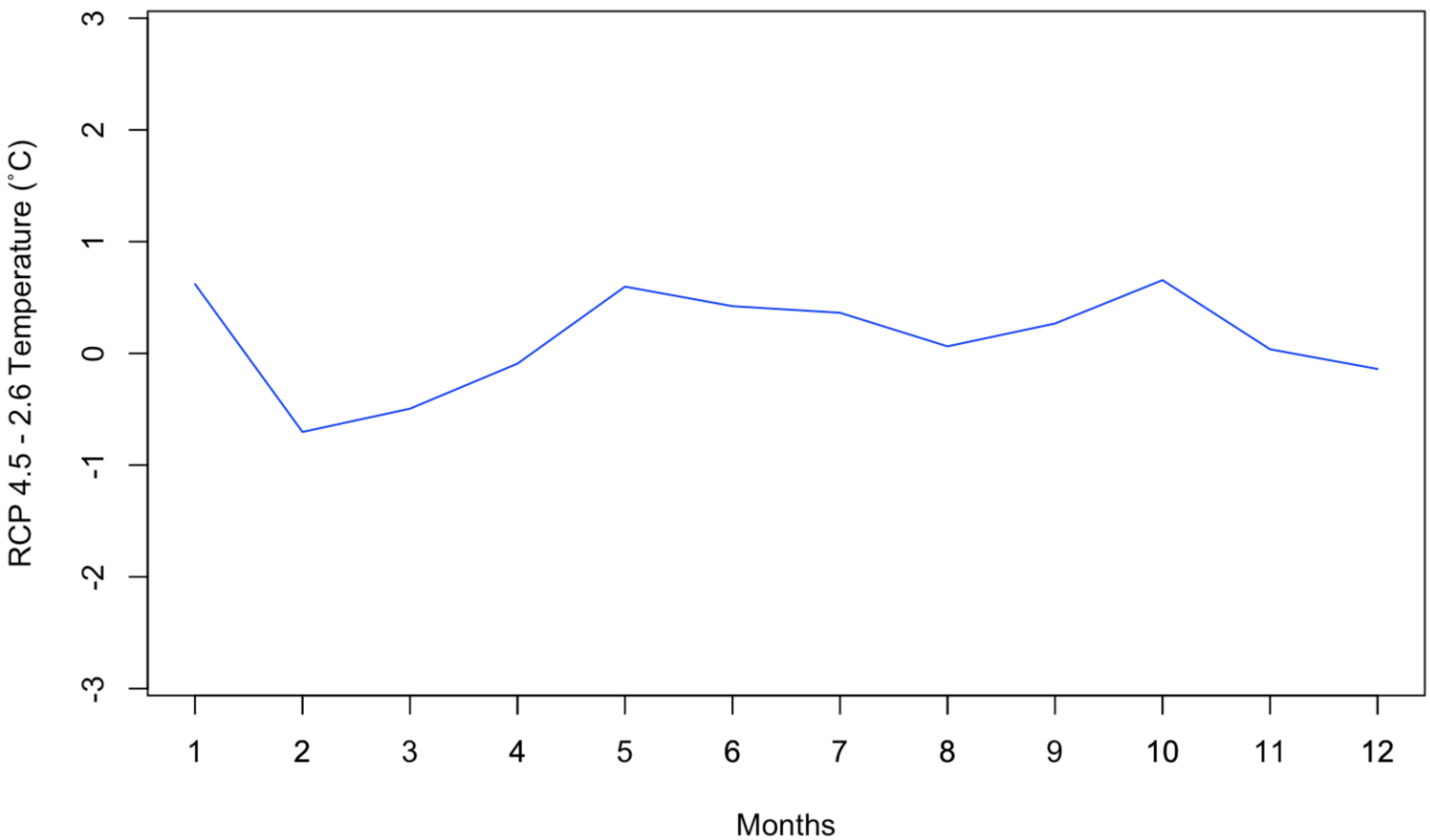
We are interested in changing the x-axis so that the months can be represented by all numbers from 1 to 12. The first argument in the axis command is "**side**", which refers to the side of the plot whose axis you want to change. The bottom x-axis is referred to as side 1 in RStudio. The other argument we will use is "**at**". The "**at**" argument tells RStudio where to draw the tick marks on the axis. Since we want to represent all months with a number, we need a tick mark to represent every number from 1 to 12.

Go to line #85 in your code and type the following:

axis(1, at=seq(1,12,1))

Here, we are using the axis command to change the tick marks on side #1, the bottom x-axis. By using **at=seq(1,12,1),** we are telling RStudio to put tick marks on every number from 1 to 12.

Highlight and run lines #84 & #85 and your plot should look like the plot in the image below.



Step 62. The plot you just created shows the average monthly temperatures for RCP 4.5 – RCP 2.6 for the first 30-year interval of 2011 to 2040. To put a second line on the graph, users need to use command **par(new=T).** This tells RStudio that you will now be adding more lines to the plot that was created on the previous line of code.

Go to line #86 of the code and type the following:

par(new=T)

Step 63. To add a second line to the plot, we need to again use the **plot** command. Since we are adding a second line to an already existing set of axes, we need to use different arguments with this **plot** command:

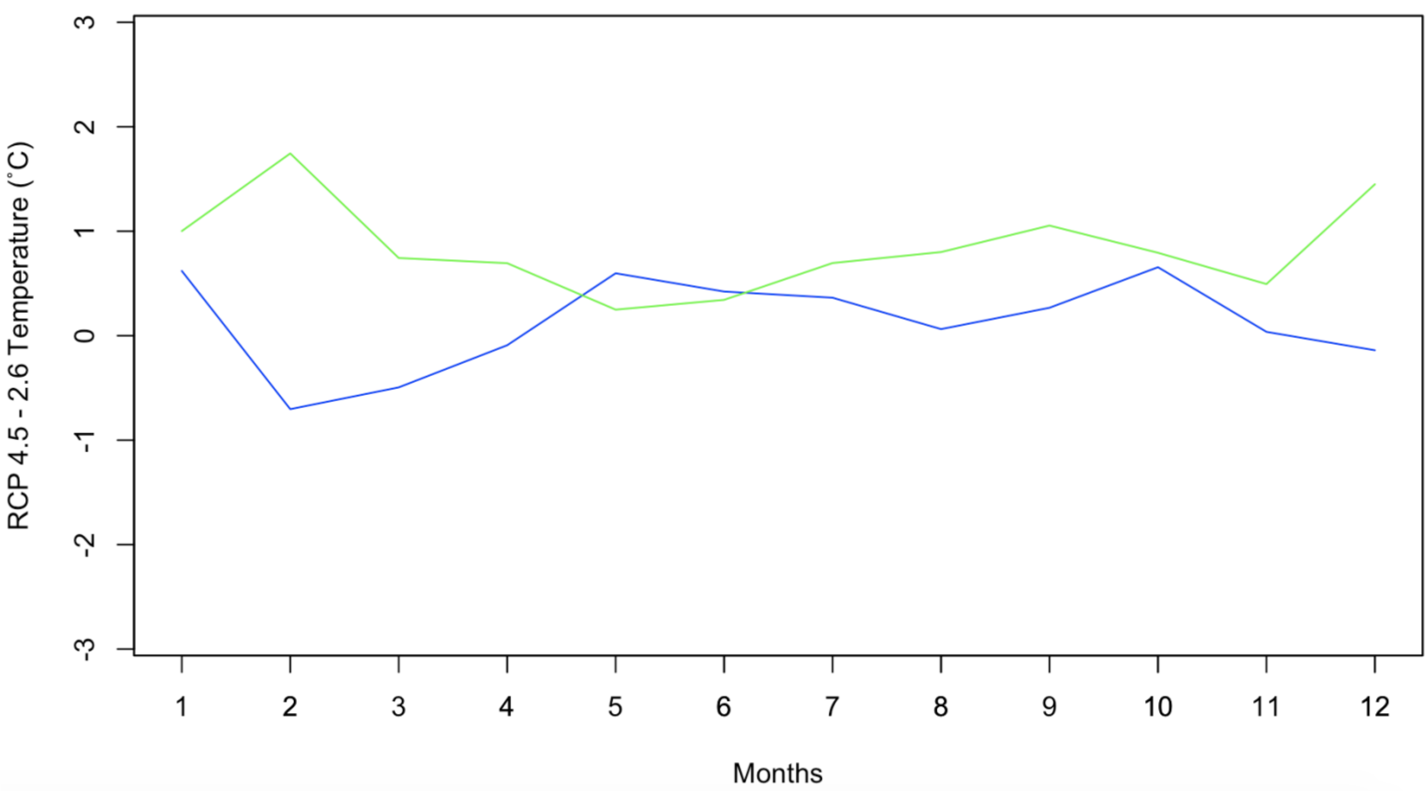
- **y = Monthly_Average_2** (The name of the dataset representing average monthly temperatures for RCP 4.5 – RCP 2.6 in the second 30-year interval).
- **type = "l"**
- **col = "green"** (We need a different color line from the blue line representing Monthly_Average_1)

- **xlab = NA (**Since we want to plot a second line on the same axes as the plot from step #59, we need the x=axis label to be NA so it does not override the x-axis label set in step #59).
- **ylab = NA (**Since we want to plot a second line on the same axes as the plot from step #59, we need the y=axis label to be NA so it does not override the y-axis label set in step #59).
- **xaxt = "n"** (This suppresses plotting values on the x-axis so that the x-axis set in step #59 is not overridden)
- **yaxt = "n"** (This suppresses plotting values on the y-axis so that the y-axis set in step #59 is not overridden)
- **ylim=c(-Max_Abs_Value,Max_Abs_Value)** (You need to tell RStudio to keep the y-axis limit the same as the previous line you graphed)

Go to line #87 of your code and type the following:

plot(Monthly_Average_2, type="l", col="green", xlab=NA, ylab=NA, xaxt="n", yaxt="n",ylim=c(-Max_Abs_Value,Max_Abs_Value))

Highlight and run lines #86 and #87 and your plot should now look like the one in the image below:



Step 64. We need to add one more line to the graph to represent the monthly averages for the last 30-year interval of 2071 to 2100.

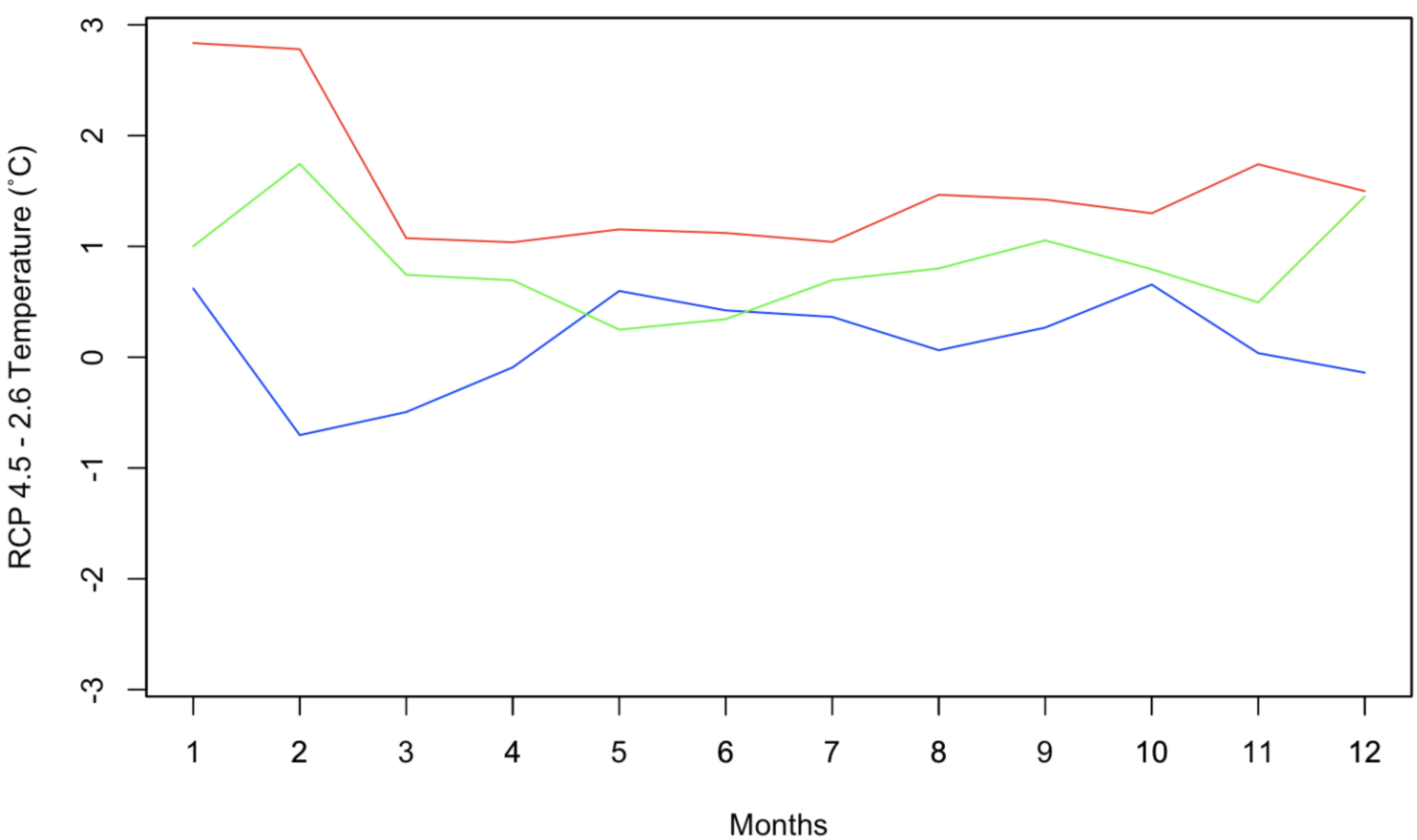
Go to line #88 of your code and type **par(new=T).**

Go to line #89 of your code and type the following:

plot(Monthly_Average_3, type="l", col="red", xlab=NA, ylab=NA, xaxt="n", yaxt="n",ylim=c(-Max_Abs_Value,Max_Abs_Value))

Here, the dataset is now **Monthly_Average_3,** and the line color is now red.

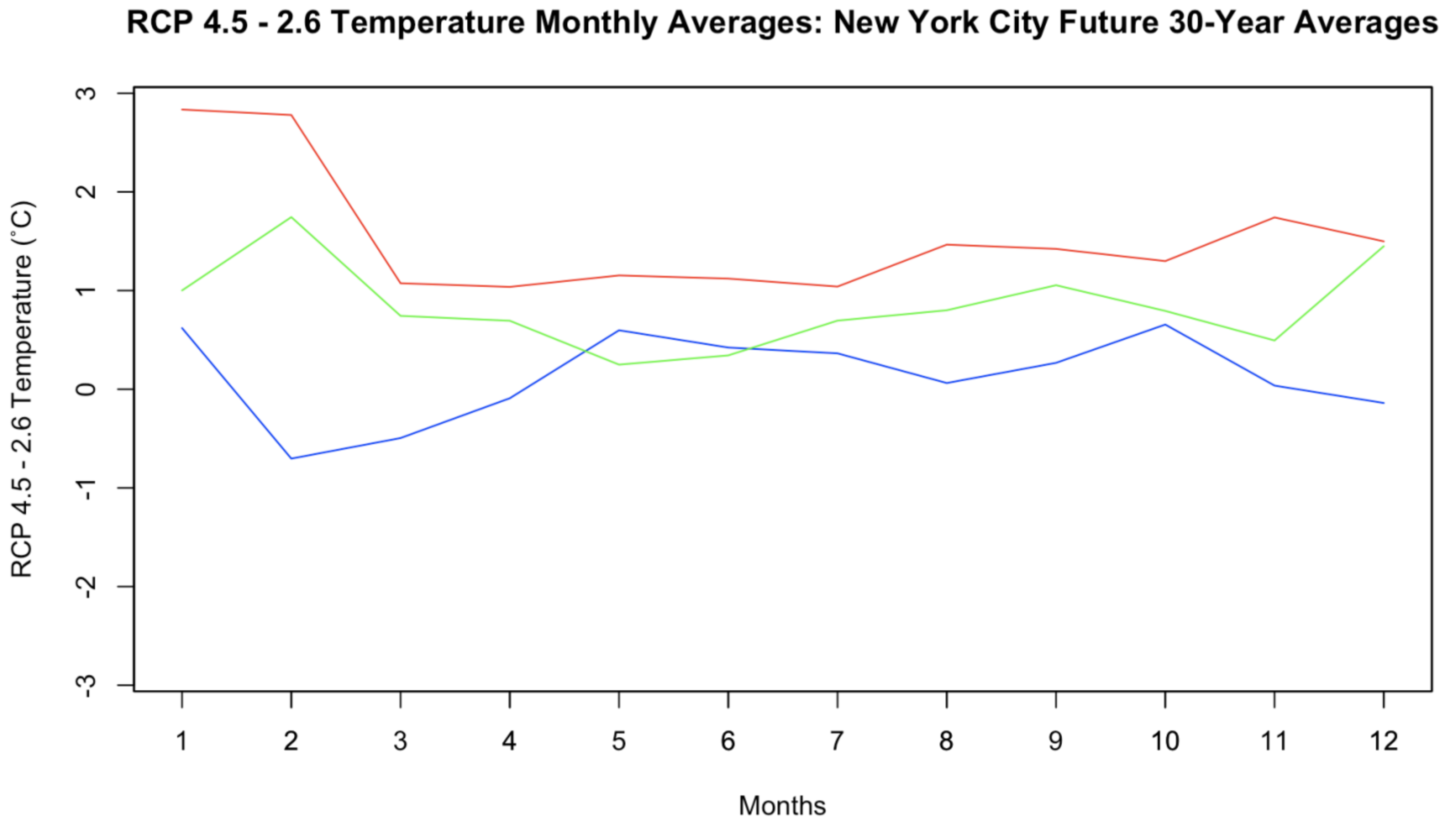
Highlight and run lines #88 and #89 and your plot should now look like the following:



Step 65. We will now learn how to put a title on the plot by using the **title** command. The only argument we need in the **title** command is the title of the graph you want in quotations. Type the following into line #90:

title("RCP 4.5 - 2.6 Temperature Monthly Averages: New York City Future 30-Year Averages")

Highlight and run line #90 and you should now see a title on the graph as shown below.



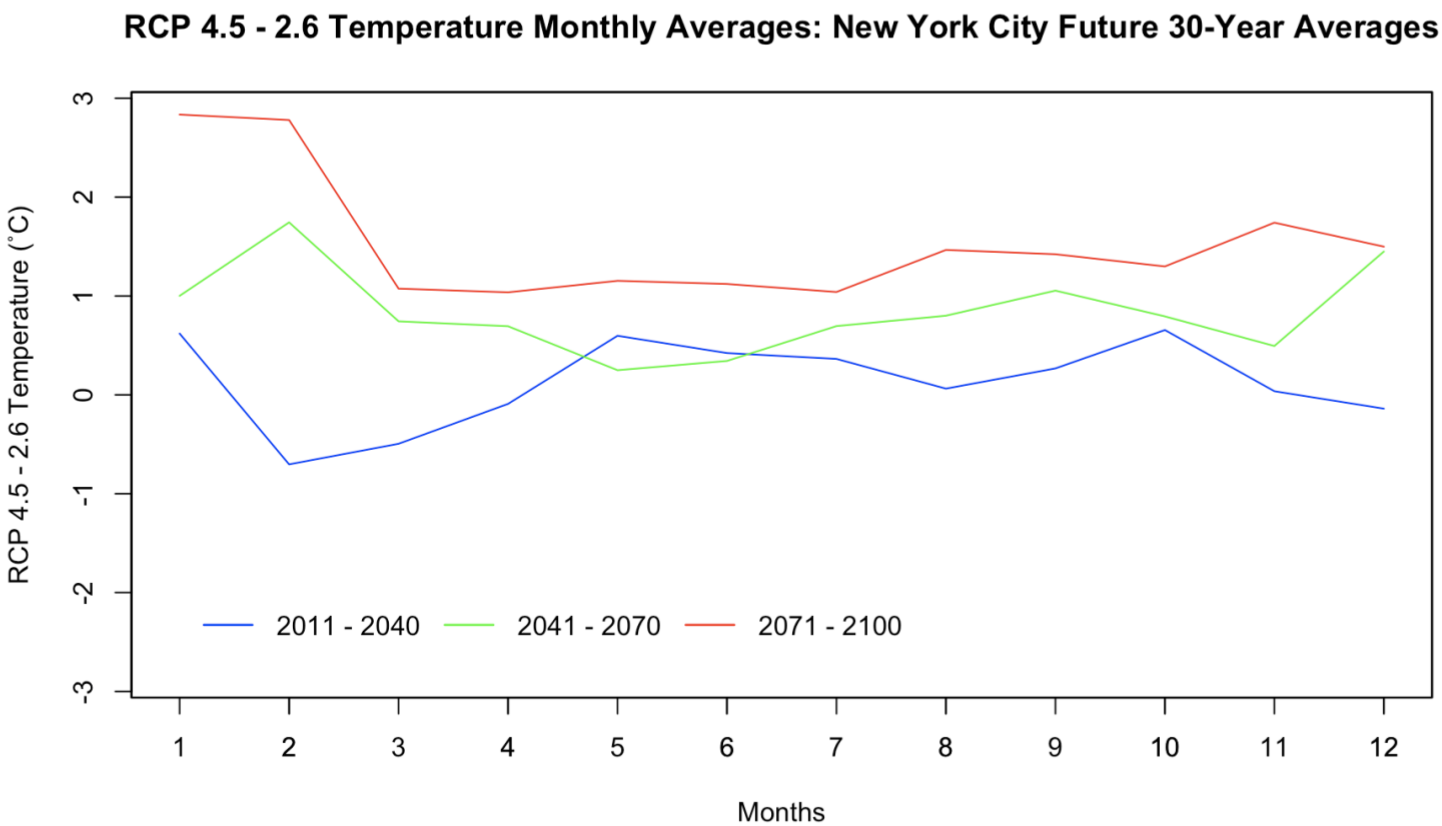
Step 66. To finalize our graph, we will learn how to put a legend on the graph using the **legend** command. This command allows users to specify the data that each line color corresponds to. Below are the arguments we will use in the **legend** command:

- **x =** 1 (This is the location on the x-axis where the legend will begin. Since the x-axis values begin at 1, that is why we are specifying that the legend begins at x = 1. This number can be changed depending on where the lines are on the graph).
- **y =** -2 (This is the location on the y-axis where the legend will begin. Here, I chose -2 because most of the data is near the top of the plot and I want the legend to be at the bottom. This number can be changed depending on where the lines are on the graph.)
- **lwd** = 1.3 (This sets the line width equal to 1.3. The default line width is 1.0)
- **legend** = c("2011 - 2040", "2041 - 2070", "2071 - 2100") (This argument specifies the labels within the legend key. The command **c** must be used, and each set of labels must be in quotations.)
- **col**= c("blue", "green", "red") (This argument creates the line colors in the legend. The order of the colors in this argument corresponds to the order of the labels set using the previous argument.)
- **bty** = "n" (This argument tells RStudio to not put a box around the legend)
- **horiz** = TRUE (This argument tells RStudio to make the legend horizontal instead of vertical, where horiz would be equal to FALSE).

Type the following into line #91 of the code:

```
legend(x=1, y=-2, lwd=1.3, legend=c("2011 - 2040", "2041 - 2070", "2071 - 2100"), col=c("blue", "green", "red"), bty="n", horiz=TRUE)
```

Highlight and run line #91 in the code to ensure there are no error statements in the **Console**.
Your plot should now look like the following:



Q16. Based on the graph, which month shows the greatest differences in RCP 4.5 – RCP 2.6 temperature amongst the three 30-year intervals? What does this mean in terms of future climate change projections?

Month: ________________________

Meaning: ____

Q17. Based on the graph, which 30-year interval experienced the greatest differences between RCP 4.5 and RCP 2.6 temperatures? Explain how you know.

30-year interval: ____

Explanation: ____

Q18. Based on the graph, which 30-year interval experienced the smallest differences between RCP 4.5 and RCP 2.6 temperatures? Explain how you know.

30-year interval: ____

Explanation: ____

Q19. In general, what can we conclude about how monthly temperatures will change overtime for the RCP 4.5 – RCP 2.6 scenario?

____

Step 67. Using the knowledge you learned from this activity thus far, create a triple line graph similar to the plot created at the end of the previous step for the RCP 8.5 – 2.6 temperature projection scenarios. For this graph, complete the following:

- Change the title of the graph to reflect the new data
- Change the y-axis range using ylim so that it is centered around zero. This will depend on the data values.
- Make each line a different color.
- Change the legend parameters so it fits nicely on your graph
- Once your plot is created, under the **Plots** tab near the bottom right of RStudio, click on **Export** and then **Save Image As** to save your image onto your computer.

Q20. In the blank space below, place the plot you created in step #67.

Q21. Based on the graph, which month shows the greatest differences in RCP 8.5 – RCP 2.6 temperature amongst the three 30-year intervals? What does this mean in terms of future climate change projections?

Month: _________________________

Meaning: ____

Q22. Based on the graph, which 30-year interval experienced the greatest differences between RCP 8.5 and RCP 2.6 temperatures? Explain how you know.

30-year interval: ____

Explanation: ____

Q23. Based on the graph, which 30-year interval experienced the smallest differences between RCP 8.5 and RCP 2.6 temperatures? Explain how you know.

30-year interval: ____

Explanation: ____

Q24. In general, what can we conclude about how monthly temperatures will change overtime for the RCP 8.5 – RCP 2.6 scenario?

____

Answers: Using RStudio: Creating Temperature Projection Graphs for New York City

Q1. What is the complete file pathway for your **RCP26_Temperature.nc** file?

These answers will vary and will depend on the specific computer the student is using. This question is included for the teacher to check for student understanding in terms of determining the correct pathway.

Q2. Why are there 1,140 time components in these datasets?

There are 1,140 time components because the data is monthly from 2006 to 2100. From the year 2006 to 2100, there are 1,140 months and therefore 1,140 time components.

Q3. Using the **Console** and the function **LatGrid**, determine the latitude grid box values for the following latitude values (remember, south latitude values are represented by negative numbers):

Latitude = 68˚N **Grid Box #** = **248**

Latitude = 25˚S **Grid Box** # = **62**

Latitude = 14˚N **Grid Box #** = **140**

Q4. Using the **Console** and the function **LonGrid_East or LonGrid_West,** determine the longitude grid box values for the following longitude values (remember, west longitude values are represented by negative numbers):

Longitude = 116˚E **Grid Box #** = **233**

Longitude = 35˚W **Grid Box** # = **650**

Longitude = 77˚W **Grid Box** # = **566**

Q5. Why do scientists use 30 years of data when analyzing temperature changes?

To calculate an accurate average 30 values are needed because using less than 30 years can result in an unreliable average, while using more than 30 years can skew results.

Q6. 30-year Interval #1: January 2011 to December 2040
January 2011 time grid box #: **61**
December 2040 time grid box #: **420**

Q7. 30-year Interval #2: January 2041 to December 2070
January 2041 time grid box #: **421**

December 2070 time grid box #: **780**

Q8. 30-year Interval #3: January 2071 to December 2100
January 2071 time grid box #: **781**
December 2100 time grid box #: **1140**

Q9. What does a positive value of RCP 4.5 – RCP 2.6 indicate?

A positive value of RCP 4.5 – RCP 2.6 indicates that the value from the RCP 4.5 scenario is higher than the RCP 2.6 scenario.

Q10. What does a negative value of RCP 4.5 – RCP 2.6 indicate?

A negative value of RCP 4.5 – RCP 2.6 indicates that the value from the RCP 4.5 scenario is lower than the RCP 2.6 scenario.

Q11. Use the **Console** to analyze the values of all monthly averages of RCP 4.5 – RCP 2.6 during the first 30-year interval.

List the names of all of the months where the average monthly temperature of the RCP 4.5 scenario was ***greater than*** the RCP 2.6 scenario for the first 30-year interval (2011 – 2040).

January, May, June, July, August, September, October, & November

List the names of all of the months where the average monthly temperature of the RCP 4.5 scenario was ***less than*** the RCP 2.6 scenario for the first 30-year interval (2011 – 2040).

February, March, April, & December

Q12. Use the **Console** to analyze the values of all monthly averages of RCP 4.5 – RCP 2.6 during the **second 30-year interval (2041 – 2070)**.

List the names of all of the months where the average monthly temperature of the RCP 4.5 scenario was ***greater than*** the RCP 2.6 scenario for the second 30-year interval (2041 – 2070).

All months of the year

List the names of all of the months where the average monthly temperature of the RCP 4.5 scenario was ***less than*** the RCP 2.6 scenario for the second 30-year interval (2041 – 2070).

No months

Q13. Use the **Console** to analyze the values of all monthly averages of RCP 4.5 – RCP 2.6 during the **third 30-year interval (2071 – 2100)**.

List the names of all of the months where the average monthly temperature of the RCP 4.5 scenario was ***greater than*** the RCP 2.6 scenario for the third 30-year interval (2071 – 2100).

All months of the year

List the names of all of the months where the average monthly temperature of the RCP 4.5 scenario was ***less than*** the RCP 2.6 scenario for the third 30-year interval (2071 – 2100).

No months

Q14. Use the Console to conduct a similar analysis to the one in step #62 for all of the months. January has been done for you as an example.

January: Which 30-year interval has the greatest difference in temperature between the RCP 4.5 – RCP 2.6 scenario? Please provide the years of the 30-year interval.

2071 – 2100

February: Which 30-year interval has the greatest difference in temperature between the RCP 4.5 – RCP 2.6 scenario? Please provide the years of the 30-year interval.

2071 – 2100

March: Which 30-year interval has the greatest difference in temperature between the RCP 4.5 – RCP 2.6 scenario? Please provide the years of the 30-year interval.

2071 – 2100

April: Which 30-year interval has the greatest difference in temperature between the RCP 4.5 – RCP 2.6 scenario? Please provide the years of the 30-year interval.

2071 – 2100

May: Which 30-year interval has the greatest difference in temperature between the RCP 4.5 – RCP 2.6 scenario? Please provide the years of the 30-year interval.

2071 – 2100

June: Which 30-year interval has the greatest difference in temperature between the RCP 4.5 – RCP 2.6 scenario? Please provide the years of the 30-year interval.

2071 – 2100

July: Which 30-year interval has the greatest difference in temperature between the RCP 4.5 – RCP 2.6 scenario? Please provide the years of the 30-year interval.

2071 – 2100

August: Which 30-year interval has the greatest difference in temperature between the RCP 4.5 – RCP 2.6 scenario? Please provide the years of the 30-year interval.

2071 – 2100

September: Which 30-year interval has the greatest difference in temperature between the RCP 4.5 – RCP 2.6 scenario? Please provide the years of the 30-year interval.

2071 – 2100

October: Which 30-year interval has the greatest difference in temperature between the RCP 4.5 – RCP 2.6 scenario? Please provide the years of the 30-year interval.

2071 – 2100

November: Which 30-year interval has the greatest difference in temperature between the RCP 4.5 – RCP 2.6 scenario? Please provide the years of the 30-year interval.

2071 – 2100

December: Which 30-year interval has the greatest difference in temperature between the RCP 4.5 – RCP 2.6 scenario? Please provide the years of the 30-year interval.

2071 – 2100

Q15. Based on your answers to Q14, what general conclusion can we make about the 30-year intervals and the difference in temperature between the RCP 4.5 and RCP 2.6 scenario?

A general conclusion is that the last 30-year interval representing 2071 to 2100 will experience greater RCP 4.5 temperatures in comparison to the other 30-year intervals. As time increases, temperature is expected to increase more in the RCP 4.5 scenario between 2071 and 2100.

Q16. Based on the graph, which month shows the greatest differences in RCP 4.5 – RCP 2.6 temperature amongst the three 30-year intervals? What does this mean in terms of future climate change projections?

Month: February

Meaning: **The month of February is expected to be the most variable in terms of future temperature projections. Winter temperature predictions could be uncertain and will greatly depend on the future greenhouse gas emissions through the RCP scenarios. Also, February is expected to have the greatest increase in temperature in the 2071 to 2100 30-year interval.**

Q17. Based on the graph, which 30-year interval experienced the greatest differences between RCP 4.5 and RCP 2.6 temperatures? Explain how you know.

30-year interval: **The last 30-year interval representing 2071 to 2100 experienced higher RCP 4.5 temperatures compared to RCP 2.6.**

Explanation: **Every value for the last 30-year interval is more positive than the other two intervals, indicating that not only is the RCP 4.5 temperature greater than RCP 2.6, but the extent to which it is greater is higher than the other 30-year intervals.**

Q18. Based on the graph, which 30-year interval experienced the smallest differences between RCP 4.5 and RCP 2.6 temperatures? Explain how you know.

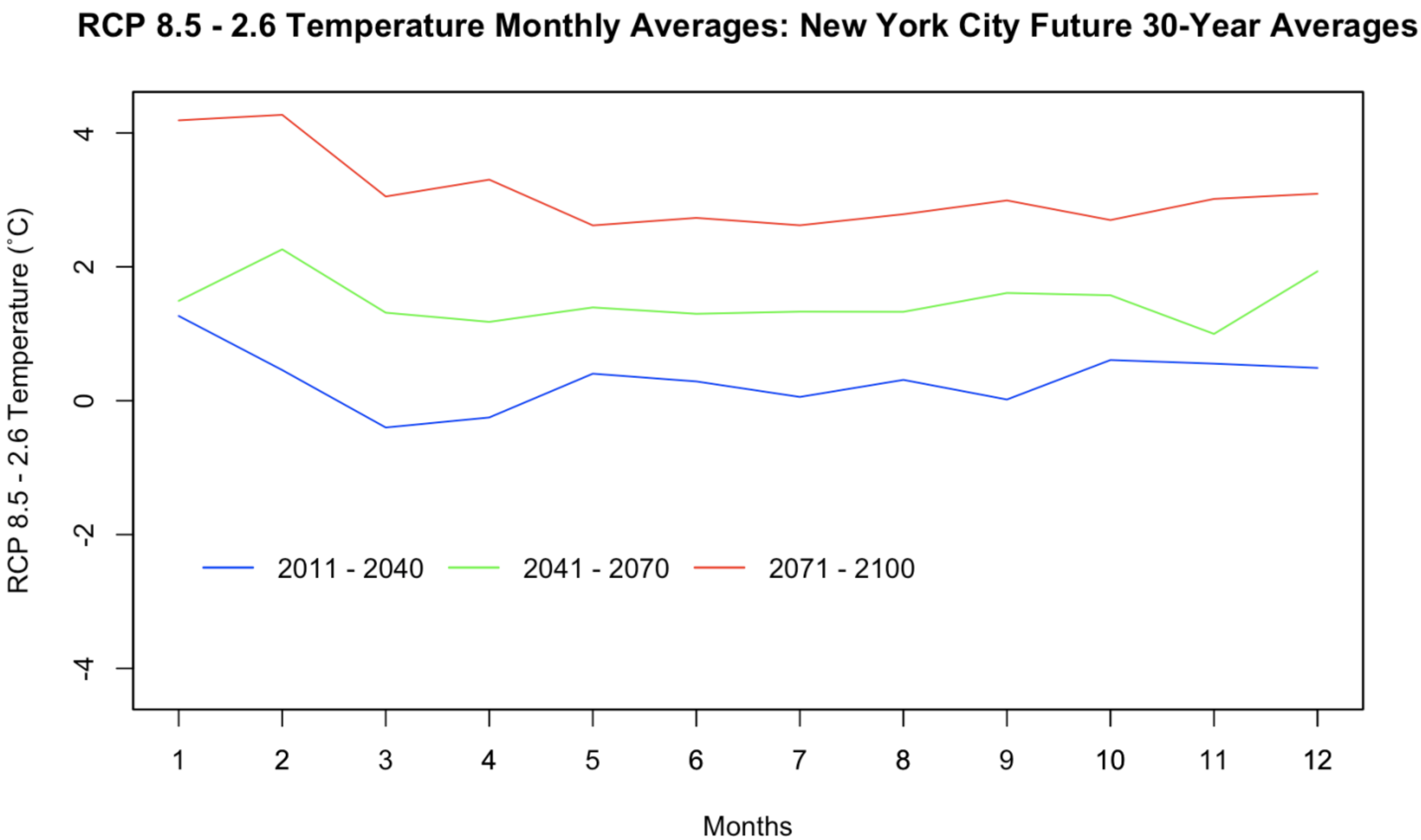
30-year interval: **The first 30-year interval representing 2011 to 2040 experienced the smallest differences between the RCP 4.5 and RCP 2.6 temperatures.**

Explanation: **Every value for the first 30-year interval is lower than the other two, except for the month of May, indicating that the difference between RCP 4.5 and RCP 2.6 temperatures was not as drastic as the other two 30-year intervals.**

Q19. In general, what can we conclude about how monthly temperatures will change overtime for the RCP 4.5 – RCP 2.6 scenario?

Overtime, the differences between the RCP 4.5 and RCP 2.6 temperatures increase for each month, indicating that RCP 4.5 temperatures become greater compared to RCP 2.6 as we go from the year 2011 to 2100. The greatest differences are in the 2071 to 2100 interval, while the smallest differences are in the 2011 to 2040 interval.

Q20. In the blank space below, place the plot you created in step #73.



Q21. Based on the graph, which month shows the greatest differences in RCP 8.5 – RCP 2.6 temperature amongst the three 30-year intervals? What does this mean in terms of future climate change projections?

Month: March

Meaning: The month of March is expected to be the most variable in terms of future temperature projections. Winter temperature predictions could be uncertain and will greatly depend on the future greenhouse gas emissions through the RCP scenarios.

Q22. Based on the graph, which 30-year interval experienced the greatest differences between RCP 8.5 and RCP 2.6 temperatures? Explain how you know.

30-year interval: The last 30-year interval representing 2071 to 2100 experienced higher RCP 8.5 temperatures compared to RCP 2.6.

Explanation: Every value for the last 30-year interval is more positive than the other two intervals, indicating that not only is the RCP 8.5 temperature greater than RCP 2.6, but the extent to which it is greater is higher than the other 30-year intervals.

Q23. Based on the graph, which 30-year interval experienced the smallest differences between RCP 8.5 and RCP 2.6 temperatures? Explain how you know.

30-year interval: **The first 30-year interval representing 2011 to 2040 experienced the smallest differences between the RCP 8.5 and RCP 2.6 temperatures.**

Explanation: **For all months of the year, the values for RCP 8.5 – RCP 2.6 are the lowest, indicating this 2011 to 2040 interval has the smallest differences in temperature for this scenario.**

Q24. In general, what can we conclude about how monthly temperatures will change overtime for the RCP 8.5 – RCP 2.6 scenario?

Overtime, the differences between the RCP 8.5 and RCP 2.6 temperatures increase for each month, indicating that RCP 8.5 temperatures become greater compared to RCP 2.6 as we go from the year 2011 to 2100. The greatest differences are in the 2071 to 2100 interval, while the smallest differences are in the 2011 to 2040 interval.

Example RScript – RCP 4.5 – 2.6 Temperature Projection Graphs

Below is an example RScript for creating the graphs from the RCP temperature projections. If you copy and paste the script into an RScript file, all of the proper colors will appear.

Note: This example script is here to guide teachers and should not be provided to the students!

```
library(ncdf4)
source("/Users/ndulaney/Documents/NASA_SMD_LessonPlans/Functions.r")
#This code will teach students how to load netCDF data into RStudio in order to create line plots of RCP temperature projection monthly average data.
#We will now learn how to load a netCDF file into RStudio.
RCP26_Temp_Data <- nc_open("/Users/ndulaney/Downloads/RCP26_Temperature.nc")
RCP45_Temp_Data <- nc_open("/Users/ndulaney/Downloads/RCP45_Temperature.nc")

#We will now learn how to extract the tas variable from the dataset.
RCP26_Temp <- ncvar_get(RCP26_Temp_Data, "tas")
RCP45_Temp <- ncvar_get(RCP45_Temp_Data, "tas")

#Create a data subset for just New York City Coordinates (40.7˚N, 74˚W)
RCP26_Temp_NYC <- RCP26_Temp[LonGrid_West(-74.0),LatGrid(40.7), ]
RCP45_Temp_NYC <- RCP45_Temp[LonGrid_West(-74.0),LatGrid(40.7), ]

#Calculate the projections from RCP 4.5 - 2.6
RCP45_RCP26_Temp_NYC <- RCP45_Temp_NYC - RCP26_Temp_NYC

#Create 30-year subsets from 2011 to 2100
#First 30-year subset will be January 2011 to December 2040
RCP45_RCP26_Temp_NYC_1 <- RCP45_RCP26_Temp_NYC[61:420]

#Second 30-year subset will be January 2041 to December 2070
RCP45_RCP26_Temp_NYC_2 <- RCP45_RCP26_Temp_NYC[421:780]

#Third 30-year subset will be January 2071 to December 2100
RCP45_RCP26_Temp_NYC_3 <- RCP45_RCP26_Temp_NYC[781:1140]

#Calculate the monthly average for each month from January 2011 to December 2040
Jan_Avg_1 <- mean(RCP45_RCP26_Temp_NYC_1[Months_Data(1)])
Feb_Avg_1 <- mean(RCP45_RCP26_Temp_NYC_1[Months_Data(2)])
Mar_Avg_1 <- mean(RCP45_RCP26_Temp_NYC_1[Months_Data(3)])
Apr_Avg_1 <- mean(RCP45_RCP26_Temp_NYC_1[Months_Data(4)])
May_Avg_1 <- mean(RCP45_RCP26_Temp_NYC_1[Months_Data(5)])
Jun_Avg_1 <- mean(RCP45_RCP26_Temp_NYC_1[Months_Data(6)])
Jul_Avg_1 <- mean(RCP45_RCP26_Temp_NYC_1[Months_Data(7)])
```

```
Aug_Avg_1 <- mean(RCP45_RCP26_Temp_NYC_1[Months_Data(8)])
Sep_Avg_1 <- mean(RCP45_RCP26_Temp_NYC_1[Months_Data(9)])
Oct_Avg_1 <- mean(RCP45_RCP26_Temp_NYC_1[Months_Data(10)])
Nov_Avg_1 <- mean(RCP45_RCP26_Temp_NYC_1[Months_Data(11)])
Dec_Avg_1 <- mean(RCP45_RCP26_Temp_NYC_1[Months_Data(12)])

#Create a vector that contains the monthly averages from January 2011 to December 2040. The length of the vector will be 12, one average value for each month of the year
Monthly_Average_1 <-
c(Jan_Avg_1,Feb_Avg_1,Mar_Avg_1,Apr_Avg_1,May_Avg_1,Jun_Avg_1,Jul_Avg_1,Aug_Avg_1,Sep_Avg_1,Oct_Avg_1,Nov_Avg_1,Dec_Avg_1)

#Calculate the monthly average for each month from January 2041 to December 2070
Jan_Avg_2 <- mean(RCP45_RCP26_Temp_NYC_2[Months_Data(1)])
Feb_Avg_2 <- mean(RCP45_RCP26_Temp_NYC_2[Months_Data(2)])
Mar_Avg_2 <- mean(RCP45_RCP26_Temp_NYC_2[Months_Data(3)])
Apr_Avg_2 <- mean(RCP45_RCP26_Temp_NYC_2[Months_Data(4)])
May_Avg_2 <- mean(RCP45_RCP26_Temp_NYC_2[Months_Data(5)])
Jun_Avg_2 <- mean(RCP45_RCP26_Temp_NYC_2[Months_Data(6)])
Jul_Avg_2 <- mean(RCP45_RCP26_Temp_NYC_2[Months_Data(7)])
Aug_Avg_2 <- mean(RCP45_RCP26_Temp_NYC_2[Months_Data(8)])
Sep_Avg_2 <- mean(RCP45_RCP26_Temp_NYC_2[Months_Data(9)])
Oct_Avg_2 <- mean(RCP45_RCP26_Temp_NYC_2[Months_Data(10)])
Nov_Avg_2 <- mean(RCP45_RCP26_Temp_NYC_2[Months_Data(11)])
Dec_Avg_2 <- mean(RCP45_RCP26_Temp_NYC_2[Months_Data(12)])

#Create a vector that contains the monthly averages from January 2011 to December 2040. The length of the vector will be 12, one average value for each month of the year
Monthly_Average_2 <-
c(Jan_Avg_2,Feb_Avg_2,Mar_Avg_2,Apr_Avg_2,May_Avg_2,Jun_Avg_2,Jul_Avg_2,Aug_Avg_2,Sep_Avg_2,Oct_Avg_2,Nov_Avg_2,Dec_Avg_2)

#Calculate the monthly average for each month from January 2071 to December 2100
Jan_Avg_3 <- mean(RCP45_RCP26_Temp_NYC_3[Months_Data(1)])
Feb_Avg_3 <- mean(RCP45_RCP26_Temp_NYC_3[Months_Data(2)])
Mar_Avg_3 <- mean(RCP45_RCP26_Temp_NYC_3[Months_Data(3)])
Apr_Avg_3 <- mean(RCP45_RCP26_Temp_NYC_3[Months_Data(4)])
May_Avg_3 <- mean(RCP45_RCP26_Temp_NYC_3[Months_Data(5)])
Jun_Avg_3 <- mean(RCP45_RCP26_Temp_NYC_3[Months_Data(6)])
Jul_Avg_3 <- mean(RCP45_RCP26_Temp_NYC_3[Months_Data(7)])
Aug_Avg_3 <- mean(RCP45_RCP26_Temp_NYC_3[Months_Data(8)])
Sep_Avg_3 <- mean(RCP45_RCP26_Temp_NYC_3[Months_Data(9)])
Oct_Avg_3 <- mean(RCP45_RCP26_Temp_NYC_3[Months_Data(10)])
Nov_Avg_3 <- mean(RCP45_RCP26_Temp_NYC_3[Months_Data(11)])
```

```
Dec_Avg_3 <- mean(RCP45_RCP26_Temp_NYC_3[Months_Data(12)])

#Create a vector that contains the monthly averages from January 2071 to December 2100. The length of the vector will be 12, one average value for each month of the year
Monthly_Average_3 <-
c(Jan_Avg_3,Feb_Avg_3,Mar_Avg_3,Apr_Avg_3,May_Avg_3,Jun_Avg_3,Jul_Avg_3,Aug_Avg_3,Sep_Avg_3,Oct_Avg_3,Nov_Avg_3,Dec_Avg_3)

#Find the maximum absolute value of all monthly average values to help set the y-axis limits when plotting
Max_Abs_Value <- max(c(Monthly_Average_1,Monthly_Average_2,Monthly_Average_3))

#Create a triple-line graph to show the differences in the seasonal cycle for the different 30-year averages
plot(Monthly_Average_1, type="l", col="blue", xlab="Months", ylab="RCP 4.5 - 2.6 Temperature (˚C)",ylim=c(-Max_Abs_Value,Max_Abs_Value))
axis(1, at=seq(1,12,1))
par(new=T)
plot(Monthly_Average_2, type="l", col="green", xlab=NA, ylab=NA, xaxt="n", yaxt="n",ylim=c(-Max_Abs_Value,Max_Abs_Value))
par(new=T)
plot(Monthly_Average_3, type="l", col="red", xlab=NA, ylab=NA, xaxt="n", yaxt="n",ylim=c(-Max_Abs_Value,Max_Abs_Value))
title("RCP 4.5 - 2.6 Temperature Monthly Averages: New York City Future 30-Year Averages")
legend(x=1, y=-2, lwd=1.3, legend=c("2011 - 2040", "2041 - 2070", "2071 - 2100"), col=c("blue", "green", "red"), bty="n", horiz=TRUE)
```

Example RScript – RCP 8.5 – 2.6 Temperature Projection Graphs

Below is an example RScript for creating the graphs from the RCP temperature projections. If you copy and paste the script into an RScript file, all of the proper colors will appear.

Note: This example script is here to guide teachers and should not be provided to the students!

```
library(ncdf4)
source("/Users/ndulaney/Documents/NASA_SMD_LessonPlans/Functions.r")
#This code will teach students how to load netCDF data into RStudio in order to create line plots of RCP temperature projection monthly average data.
#We will now learn how to load a netCDF file into RStudio.
RCP26_Temp_Data <- nc_open("/Users/ndulaney/Downloads/RCP26_Temperature.nc")
RCP85_Temp_Data <- nc_open("/Users/ndulaney/Downloads/RCP85_Temperature.nc")

#We will now learn how to extract the tas variable from the dataset.
RCP26_Temp <- ncvar_get(RCP26_Temp_Data, "tas")
RCP85_Temp <- ncvar_get(RCP85_Temp_Data, "tas")

#Create a data subset for just New York City Coordinates (40.7˚N, 74˚W)
RCP26_Temp_NYC <- RCP26_Temp[LonGrid_West(-74.0),LatGrid(40.7), ]
RCP85_Temp_NYC <- RCP85_Temp[LonGrid_West(-74.0),LatGrid(40.7), ]

#Calculate the projections from RCP 8.5 - 2.6
RCP85_RCP26_Temp_NYC <- RCP85_Temp_NYC - RCP26_Temp_NYC

#Create 30-year subsets from 2011 to 2100
#First 30-year subset will be January 2011 to December 2040
RCP85_RCP26_Temp_NYC_1 <- RCP85_RCP26_Temp_NYC[61:420]

#Second 30-year subset will be January 2041 to December 2070
RCP85_RCP26_Temp_NYC_2 <- RCP85_RCP26_Temp_NYC[421:780]

#Third 30-year subset will be January 2071 to December 2100
RCP85_RCP26_Temp_NYC_3 <- RCP85_RCP26_Temp_NYC[781:1140]

#Calculate the monthly average for each month from January 2011 to December 2040
Jan_Avg_1 <- mean(RCP85_RCP26_Temp_NYC_1[Months_Data(1)])
Feb_Avg_1 <- mean(RCP85_RCP26_Temp_NYC_1[Months_Data(2)])
Mar_Avg_1 <- mean(RCP85_RCP26_Temp_NYC_1[Months_Data(3)])
Apr_Avg_1 <- mean(RCP85_RCP26_Temp_NYC_1[Months_Data(4)])
May_Avg_1 <- mean(RCP85_RCP26_Temp_NYC_1[Months_Data(5)])
Jun_Avg_1 <- mean(RCP85_RCP26_Temp_NYC_1[Months_Data(6)])
```

```
Jul_Avg_1 <- mean(RCP85_RCP26_Temp_NYC_1[Months_Data(7)])
Aug_Avg_1 <- mean(RCP85_RCP26_Temp_NYC_1[Months_Data(8)])
Sep_Avg_1 <- mean(RCP85_RCP26_Temp_NYC_1[Months_Data(9)])
Oct_Avg_1 <- mean(RCP85_RCP26_Temp_NYC_1[Months_Data(10)])
Nov_Avg_1 <- mean(RCP85_RCP26_Temp_NYC_1[Months_Data(11)])
Dec_Avg_1 <- mean(RCP85_RCP26_Temp_NYC_1[Months_Data(12)])

#Create a vector that contains the monthly averages from January 2011 to December 2040. The length of the vector will be 12, one average value for each month of the year
Monthly_Average_1 <-
c(Jan_Avg_1,Feb_Avg_1,Mar_Avg_1,Apr_Avg_1,May_Avg_1,Jun_Avg_1,Jul_Avg_1,Aug_Avg_1,Sep_Avg_1,Oct_Avg_1,Nov_Avg_1,Dec_Avg_1)

#Calculate the monthly average for each month from January 2041 to December 2070
Jan_Avg_2 <- mean(RCP85_RCP26_Temp_NYC_2[Months_Data(1)])
Feb_Avg_2 <- mean(RCP85_RCP26_Temp_NYC_2[Months_Data(2)])
Mar_Avg_2 <- mean(RCP85_RCP26_Temp_NYC_2[Months_Data(3)])
Apr_Avg_2 <- mean(RCP85_RCP26_Temp_NYC_2[Months_Data(4)])
May_Avg_2 <- mean(RCP85_RCP26_Temp_NYC_2[Months_Data(5)])
Jun_Avg_2 <- mean(RCP85_RCP26_Temp_NYC_2[Months_Data(6)])
Jul_Avg_2 <- mean(RCP85_RCP26_Temp_NYC_2[Months_Data(7)])
Aug_Avg_2 <- mean(RCP85_RCP26_Temp_NYC_2[Months_Data(8)])
Sep_Avg_2 <- mean(RCP85_RCP26_Temp_NYC_2[Months_Data(9)])
Oct_Avg_2 <- mean(RCP85_RCP26_Temp_NYC_2[Months_Data(10)])
Nov_Avg_2 <- mean(RCP85_RCP26_Temp_NYC_2[Months_Data(11)])
Dec_Avg_2 <- mean(RCP85_RCP26_Temp_NYC_2[Months_Data(12)])

#Create a vector that contains the monthly averages from January 2011 to December 2040. The length of the vector will be 12, one average value for each month of the year
Monthly_Average_2 <-
c(Jan_Avg_2,Feb_Avg_2,Mar_Avg_2,Apr_Avg_2,May_Avg_2,Jun_Avg_2,Jul_Avg_2,Aug_Avg_2,Sep_Avg_2,Oct_Avg_2,Nov_Avg_2,Dec_Avg_2)

#Calculate the monthly average for each month from January 2071 to December 2100
Jan_Avg_3 <- mean(RCP85_RCP26_Temp_NYC_3[Months_Data(1)])
Feb_Avg_3 <- mean(RCP85_RCP26_Temp_NYC_3[Months_Data(2)])
Mar_Avg_3 <- mean(RCP85_RCP26_Temp_NYC_3[Months_Data(3)])
Apr_Avg_3 <- mean(RCP85_RCP26_Temp_NYC_3[Months_Data(4)])
May_Avg_3 <- mean(RCP85_RCP26_Temp_NYC_3[Months_Data(5)])
Jun_Avg_3 <- mean(RCP85_RCP26_Temp_NYC_3[Months_Data(6)])
Jul_Avg_3 <- mean(RCP85_RCP26_Temp_NYC_3[Months_Data(7)])
Aug_Avg_3 <- mean(RCP85_RCP26_Temp_NYC_3[Months_Data(8)])
Sep_Avg_3 <- mean(RCP85_RCP26_Temp_NYC_3[Months_Data(9)])
Oct_Avg_3 <- mean(RCP85_RCP26_Temp_NYC_3[Months_Data(10)])
```

```
Nov_Avg_3 <- mean(RCP85_RCP26_Temp_NYC_3[Months_Data(11)])
Dec_Avg_3 <- mean(RCP85_RCP26_Temp_NYC_3[Months_Data(12)])

#Create a vector that contains the monthly averages from January 2071 to December 2100. The length of the vector will be 12, one average value for each month of the year
Monthly_Average_3 <-
c(Jan_Avg_3,Feb_Avg_3,Mar_Avg_3,Apr_Avg_3,May_Avg_3,Jun_Avg_3,Jul_Avg_3,Aug_Avg_3,Sep_Avg_3,Oct_Avg_3,Nov_Avg_3,Dec_Avg_3)

#Find the maximum absolute value of all monthly average values to help set the y-axis limits when plotting
Max_Abs_Value <- max(c(Monthly_Average_1,Monthly_Average_2,Monthly_Average_3))

#Create a triple-line graph to show the differences in the seasonal cycle for the different 30-year averages
plot(Monthly_Average_1, type="l", col="blue", xlab="Months", ylab="RCP 8.5 - 2.6 Temperature (˚C)",ylim=c(-Max_Abs_Value,Max_Abs_Value))
axis(1, at=seq(1,12,1))
par(new=T)
plot(Monthly_Average_2, type="l", col="green", xlab=NA, ylab=NA, xaxt="n", yaxt="n",ylim=c(-Max_Abs_Value,Max_Abs_Value))
par(new=T)
plot(Monthly_Average_3, type="l", col="red", xlab=NA, ylab=NA, xaxt="n", yaxt="n",ylim=c(-Max_Abs_Value,Max_Abs_Value))
title("RCP 8.5 - 2.6 Temperature Monthly Averages: New York City Future 30-Year Averages")
legend(x=1, y=-2, lwd=1.3, legend=c("2011 - 2040", "2041 - 2070", "2071 - 2100"), col=c("blue", "green", "red"), bty="n", horiz=TRUE)
```

Coding Challenges Activity

Directions: This activity is created for students who complete the **Using RStudio: Creating Temperature Projection Graphs for New York City** quickly and could use more of a challenge.

Challenge Task #1

Lines #29 to #78 of the RScript are designated to calculate monthly average temperatures for each 30-year interval. There is a more efficient way to calculate the monthly averages while using significantly less lines of code. Using the Help window in RStudio or other resources on the internet, determine how to calculate the monthly average temperatures for each 30-year subset by using a **for loop**. The result still needs to be three different vectors, each with a length of 12, that contain the monthly average temperature values for each 30-year interval.

Challenge Task #2

Determine how to change the values on the x-axis that represent months 1 through 12 to month names abbreviated by their first three letters, such as Jan, Feb, Mar, etc.

Data Table for Longitude, Latitude, and Time Grid Boxes

For teacher use only: Below is a data table of latitude and longitude measurements and month-year combinations that correspond to their grid box values. Although the functions in **Functions.R** can be used to determine the proper grid box values, this data table is available for teachers to access, if necessary.

Please note that positive longitudes represent degrees east and negative longitudes represent degrees west. Please note that positive latitudes represent degrees north and negative latitudes represent degrees south.

Longitude Grid Box #	Longitude in ˚	Latitude Grid Box #	Latitude in ˚	Time Grid Box #	Month & Year	Time Grid Box #	Month & Year
1	0.25	1	-55.25	1	Jan-06	721	Jan-66
2	0.75	2	-54.75	2	Feb-06	722	Feb-66
3	1.25	3	-54.25	3	Mar-06	723	Mar-66
4	1.75	4	-53.75	4	Apr-06	724	Apr-66
5	2.25	5	-53.25	5	May-06	725	May-66
6	2.75	6	-52.75	6	Jun-06	726	Jun-66
7	3.25	7	-52.25	7	Jul-06	727	Jul-66
8	3.75	8	-51.75	8	Aug-06	728	Aug-66
9	4.25	9	-51.25	9	Sep-06	729	Sep-66
10	4.75	10	-50.75	10	Oct-06	730	Oct-66
11	5.25	11	-50.25	11	Nov-06	731	Nov-66
12	5.75	12	-49.75	12	Dec-06	732	Dec-66
13	6.25	13	-49.25	13	Jan-07	733	Jan-67
14	6.75	14	-48.75	14	Feb-07	734	Feb-67
15	7.25	15	-48.25	15	Mar-07	735	Mar-67
16	7.75	16	-47.75	16	Apr-07	736	Apr-67
17	8.25	17	-47.25	17	May-07	737	May-67
18	8.75	18	-46.75	18	Jun-07	738	Jun-67
19	9.25	19	-46.25	19	Jul-07	739	Jul-67
20	9.75	20	-45.75	20	Aug-07	740	Aug-67
21	10.25	21	-45.25	21	Sep-07	741	Sep-67
22	10.75	22	-44.75	22	Oct-07	742	Oct-67
23	11.25	23	-44.25	23	Nov-07	743	Nov-67
24	11.75	24	-43.75	24	Dec-07	744	Dec-67
25	12.25	25	-43.25	25	Jan-08	745	Jan-68
26	12.75	26	-42.75	26	Feb-08	746	Feb-68
27	13.25	27	-42.25	27	Mar-08	747	Mar-68
28	13.75	28	-41.75	28	Apr-08	748	Apr-68
29	14.25	29	-41.25	29	May-08	749	May-68
30	14.75	30	-40.75	30	Jun-08	750	Jun-68
31	15.25	31	-40.25	31	Jul-08	751	Jul-68

Longitude Grid Box #	Longitude in °	Latitude Grid Box #	Latitude in °	Time Grid Box #	Month & Year	Time Grid Box #	Month & Year
32	15.75	32	-39.75	32	Aug-08	752	Aug-68
33	16.25	33	-39.25	33	Sep-08	753	Sep-68
34	16.75	34	-38.75	34	Oct-08	754	Oct-68
35	17.25	35	-38.25	35	Nov-08	755	Nov-68
36	17.75	36	-37.75	36	Dec-08	756	Dec-68
37	18.25	37	-37.25	37	Jan-09	757	Jan-69
38	18.75	38	-36.75	38	Feb-09	758	Feb-69
39	19.25	39	-36.25	39	Mar-09	759	Mar-69
40	19.75	40	-35.75	40	Apr-09	760	Apr-69
41	20.25	41	-35.25	41	May-09	761	May-69
42	20.75	42	-34.75	42	Jun-09	762	Jun-69
43	21.25	43	-34.25	43	Jul-09	763	Jul-69
44	21.75	44	-33.75	44	Aug-09	764	Aug-69
45	22.25	45	-33.25	45	Sep-09	765	Sep-69
46	22.75	46	-32.75	46	Oct-09	766	Oct-69
47	23.25	47	-32.25	47	Nov-09	767	Nov-69
48	23.75	48	-31.75	48	Dec-09	768	Dec-69
49	24.25	49	-31.25	49	Jan-10	769	Jan-70
50	24.75	50	-30.75	50	Feb-10	770	Feb-70
51	25.25	51	-30.25	51	Mar-10	771	Mar-70
52	25.75	52	-29.75	52	Apr-10	772	Apr-70
53	26.25	53	-29.25	53	May-10	773	May-70
54	26.75	54	-28.75	54	Jun-10	774	Jun-70
55	27.25	55	-28.25	55	Jul-10	775	Jul-70
56	27.75	56	-27.75	56	Aug-10	776	Aug-70
57	28.25	57	-27.25	57	Sep-10	777	Sep-70
58	28.75	58	-26.75	58	Oct-10	778	Oct-70
59	29.25	59	-26.25	59	Nov-10	779	Nov-70
60	29.75	60	-25.75	60	Dec-10	780	Dec-70
61	30.25	61	-25.25	61	Jan-11	781	Jan-71
62	30.75	62	-24.75	62	Feb-11	782	Feb-71
63	31.25	63	-24.25	63	Mar-11	783	Mar-71
64	31.75	64	-23.75	64	Apr-11	784	Apr-71
65	32.25	65	-23.25	65	May-11	785	May-71
66	32.75	66	-22.75	66	Jun-11	786	Jun-71
67	33.25	67	-22.25	67	Jul-11	787	Jul-71
68	33.75	68	-21.75	68	Aug-11	788	Aug-71
69	34.25	69	-21.25	69	Sep-11	789	Sep-71
70	34.75	70	-20.75	70	Oct-11	790	Oct-71
71	35.25	71	-20.25	71	Nov-11	791	Nov-71

Longitude Grid Box #	Longitude in ˚	Latitude Grid Box #	Latitude in ˚	Time Grid Box #	Month & Year	Time Grid Box #	Month & Year
72	35.75	72	-19.75	72	Dec-11	792	Dec-71
73	36.25	73	-19.25	73	Jan-12	793	Jan-72
74	36.75	74	-18.75	74	Feb-12	794	Feb-72
75	37.25	75	-18.25	75	Mar-12	795	Mar-72
76	37.75	76	-17.75	76	Apr-12	796	Apr-72
77	38.25	77	-17.25	77	May-12	797	May-72
78	38.75	78	-16.75	78	Jun-12	798	Jun-72
79	39.25	79	-16.25	79	Jul-12	799	Jul-72
80	39.75	80	-15.75	80	Aug-12	800	Aug-72
81	40.25	81	-15.25	81	Sep-12	801	Sep-72
82	40.75	82	-14.75	82	Oct-12	802	Oct-72
83	41.25	83	-14.25	83	Nov-12	803	Nov-72
84	41.75	84	-13.75	84	Dec-12	804	Dec-72
85	42.25	85	-13.25	85	Jan-13	805	Jan-73
86	42.75	86	-12.75	86	Feb-13	806	Feb-73
87	43.25	87	-12.25	87	Mar-13	807	Mar-73
88	43.75	88	-11.75	88	Apr-13	808	Apr-73
89	44.25	89	-11.25	89	May-13	809	May-73
90	44.75	90	-10.75	90	Jun-13	810	Jun-73
91	45.25	91	-10.25	91	Jul-13	811	Jul-73
92	45.75	92	-9.75	92	Aug-13	812	Aug-73
93	46.25	93	-9.25	93	Sep-13	813	Sep-73
94	46.75	94	-8.75	94	Oct-13	814	Oct-73
95	47.25	95	-8.25	95	Nov-13	815	Nov-73
96	47.75	96	-7.75	96	Dec-13	816	Dec-73
97	48.25	97	-7.25	97	Jan-14	817	Jan-74
98	48.75	98	-6.75	98	Feb-14	818	Feb-74
99	49.25	99	-6.25	99	Mar-14	819	Mar-74
100	49.75	100	-5.75	100	Apr-14	820	Apr-74
101	50.25	101	-5.25	101	May-14	821	May-74
102	50.75	102	-4.75	102	Jun-14	822	Jun-74
103	51.25	103	-4.25	103	Jul-14	823	Jul-74
104	51.75	104	-3.75	104	Aug-14	824	Aug-74
105	52.25	105	-3.25	105	Sep-14	825	Sep-74
106	52.75	106	-2.75	106	Oct-14	826	Oct-74
107	53.25	107	-2.25	107	Nov-14	827	Nov-74
108	53.75	108	-1.75	108	Dec-14	828	Dec-74
109	54.25	109	-1.25	109	Jan-15	829	Jan-75
110	54.75	110	-0.75	110	Feb-15	830	Feb-75
111	55.25	111	-0.25	111	Mar-15	831	Mar-75

Longitude Grid Box #	Longitude in ˚	Latitude Grid Box #	Latitude in ˚	Time Grid Box #	Month & Year	Time Grid Box #	Month & Year
112	55.75	112	0.25	112	Apr-15	832	Apr-75
113	56.25	113	0.75	113	May-15	833	May-75
114	56.75	114	1.25	114	Jun-15	834	Jun-75
115	57.25	115	1.75	115	Jul-15	835	Jul-75
116	57.75	116	2.25	116	Aug-15	836	Aug-75
117	58.25	117	2.75	117	Sep-15	837	Sep-75
118	58.75	118	3.25	118	Oct-15	838	Oct-75
119	59.25	119	3.75	119	Nov-15	839	Nov-75
120	59.75	120	4.25	120	Dec-15	840	Dec-75
121	60.25	121	4.75	121	Jan-16	841	Jan-76
122	60.75	122	5.25	122	Feb-16	842	Feb-76
123	61.25	123	5.75	123	Mar-16	843	Mar-76
124	61.75	124	6.25	124	Apr-16	844	Apr-76
125	62.25	125	6.75	125	May-16	845	May-76
126	62.75	126	7.25	126	Jun-16	846	Jun-76
127	63.25	127	7.75	127	Jul-16	847	Jul-76
128	63.75	128	8.25	128	Aug-16	848	Aug-76
129	64.25	129	8.75	129	Sep-16	849	Sep-76
130	64.75	130	9.25	130	Oct-16	850	Oct-76
131	65.25	131	9.75	131	Nov-16	851	Nov-76
132	65.75	132	10.25	132	Dec-16	852	Dec-76
133	66.25	133	10.75	133	Jan-17	853	Jan-77
134	66.75	134	11.25	134	Feb-17	854	Feb-77
135	67.25	135	11.75	135	Mar-17	855	Mar-77
136	67.75	136	12.25	136	Apr-17	856	Apr-77
137	68.25	137	12.75	137	May-17	857	May-77
138	68.75	138	13.25	138	Jun-17	858	Jun-77
139	69.25	139	13.75	139	Jul-17	859	Jul-77
140	69.75	140	14.25	140	Aug-17	860	Aug-77
141	70.25	141	14.75	141	Sep-17	861	Sep-77
142	70.75	142	15.25	142	Oct-17	862	Oct-77
143	71.25	143	15.75	143	Nov-17	863	Nov-77
144	71.75	144	16.25	144	Dec-17	864	Dec-77
145	72.25	145	16.75	145	Jan-18	865	Jan-78
146	72.75	146	17.25	146	Feb-18	866	Feb-78
147	73.25	147	17.75	147	Mar-18	867	Mar-78
148	73.75	148	18.25	148	Apr-18	868	Apr-78
149	74.25	149	18.75	149	May-18	869	May-78
150	74.75	150	19.25	150	Jun-18	870	Jun-78
151	75.25	151	19.75	151	Jul-18	871	Jul-78

Longitude Grid Box #	Longitude in ˚	Latitude Grid Box #	Latitude in ˚	Time Grid Box #	Month & Year	Time Grid Box #	Month & Year
152	75.75	152	20.25	152	Aug-18	872	Aug-78
153	76.25	153	20.75	153	Sep-18	873	Sep-78
154	76.75	154	21.25	154	Oct-18	874	Oct-78
155	77.25	155	21.75	155	Nov-18	875	Nov-78
156	77.75	156	22.25	156	Dec-18	876	Dec-78
157	78.25	157	22.75	157	Jan-19	877	Jan-79
158	78.75	158	23.25	158	Feb-19	878	Feb-79
159	79.25	159	23.75	159	Mar-19	879	Mar-79
160	79.75	160	24.25	160	Apr-19	880	Apr-79
161	80.25	161	24.75	161	May-19	881	May-79
162	80.75	162	25.25	162	Jun-19	882	Jun-79
163	81.25	163	25.75	163	Jul-19	883	Jul-79
164	81.75	164	26.25	164	Aug-19	884	Aug-79
165	82.25	165	26.75	165	Sep-19	885	Sep-79
166	82.75	166	27.25	166	Oct-19	886	Oct-79
167	83.25	167	27.75	167	Nov-19	887	Nov-79
168	83.75	168	28.25	168	Dec-19	888	Dec-79
169	84.25	169	28.75	169	Jan-20	889	Jan-80
170	84.75	170	29.25	170	Feb-20	890	Feb-80
171	85.25	171	29.75	171	Mar-20	891	Mar-80
172	85.75	172	30.25	172	Apr-20	892	Apr-80
173	86.25	173	30.75	173	May-20	893	May-80
174	86.75	174	31.25	174	Jun-20	894	Jun-80
175	87.25	175	31.75	175	Jul-20	895	Jul-80
176	87.75	176	32.25	176	Aug-20	896	Aug-80
177	88.25	177	32.75	177	Sep-20	897	Sep-80
178	88.75	178	33.25	178	Oct-20	898	Oct-80
179	89.25	179	33.75	179	Nov-20	899	Nov-80
180	89.75	180	34.25	180	Dec-20	900	Dec-80
181	90.25	181	34.75	181	Jan-21	901	Jan-81
182	90.75	182	35.25	182	Feb-21	902	Feb-81
183	91.25	183	35.75	183	Mar-21	903	Mar-81
184	91.75	184	36.25	184	Apr-21	904	Apr-81
185	92.25	185	36.75	185	May-21	905	May-81
186	92.75	186	37.25	186	Jun-21	906	Jun-81
187	93.25	187	37.75	187	Jul-21	907	Jul-81
188	93.75	188	38.25	188	Aug-21	908	Aug-81
189	94.25	189	38.75	189	Sep-21	909	Sep-81
190	94.75	190	39.25	190	Oct-21	910	Oct-81
191	95.25	191	39.75	191	Nov-21	911	Nov-81

Longitude Grid Box #	Longitude in ˚	Latitude Grid Box #	Latitude in ˚	Time Grid Box #	Month & Year	Time Grid Box #	Month & Year
192	95.75	192	40.25	192	Dec-21	912	Dec-81
193	96.25	193	40.75	193	Jan-22	913	Jan-82
194	96.75	194	41.25	194	Feb-22	914	Feb-82
195	97.25	195	41.75	195	Mar-22	915	Mar-82
196	97.75	196	42.25	196	Apr-22	916	Apr-82
197	98.25	197	42.75	197	May-22	917	May-82
198	98.75	198	43.25	198	Jun-22	918	Jun-82
199	99.25	199	43.75	199	Jul-22	919	Jul-82
200	99.75	200	44.25	200	Aug-22	920	Aug-82
201	100.25	201	44.75	201	Sep-22	921	Sep-82
202	100.75	202	45.25	202	Oct-22	922	Oct-82
203	101.25	203	45.75	203	Nov-22	923	Nov-82
204	101.75	204	46.25	204	Dec-22	924	Dec-82
205	102.25	205	46.75	205	Jan-23	925	Jan-83
206	102.75	206	47.25	206	Feb-23	926	Feb-83
207	103.25	207	47.75	207	Mar-23	927	Mar-83
208	103.75	208	48.25	208	Apr-23	928	Apr-83
209	104.25	209	48.75	209	May-23	929	May-83
210	104.75	210	49.25	210	Jun-23	930	Jun-83
211	105.25	211	49.75	211	Jul-23	931	Jul-83
212	105.75	212	50.25	212	Aug-23	932	Aug-83
213	106.25	213	50.75	213	Sep-23	933	Sep-83
214	106.75	214	51.25	214	Oct-23	934	Oct-83
215	107.25	215	51.75	215	Nov-23	935	Nov-83
216	107.75	216	52.25	216	Dec-23	936	Dec-83
217	108.25	217	52.75	217	Jan-24	937	Jan-84
218	108.75	218	53.25	218	Feb-24	938	Feb-84
219	109.25	219	53.75	219	Mar-24	939	Mar-84
220	109.75	220	54.25	220	Apr-24	940	Apr-84
221	110.25	221	54.75	221	May-24	941	May-84
222	110.75	222	55.25	222	Jun-24	942	Jun-84
223	111.25	223	55.75	223	Jul-24	943	Jul-84
224	111.75	224	56.25	224	Aug-24	944	Aug-84
225	112.25	225	56.75	225	Sep-24	945	Sep-84
226	112.75	226	57.25	226	Oct-24	946	Oct-84
227	113.25	227	57.75	227	Nov-24	947	Nov-84
228	113.75	228	58.25	228	Dec-24	948	Dec-84
229	114.25	229	58.75	229	Jan-25	949	Jan-85
230	114.75	230	59.25	230	Feb-25	950	Feb-85
231	115.25	231	59.75	231	Mar-25	951	Mar-85

Longitude Grid Box #	Longitude in °	Latitude Grid Box #	Latitude in °	Time Grid Box #	Month & Year	Time Grid Box #	Month & Year
232	115.75	232	60.25	232	Apr-25	952	Apr-85
233	116.25	233	60.75	233	May-25	953	May-85
234	116.75	234	61.25	234	Jun-25	954	Jun-85
235	117.25	235	61.75	235	Jul-25	955	Jul-85
236	117.75	236	62.25	236	Aug-25	956	Aug-85
237	118.25	237	62.75	237	Sep-25	957	Sep-85
238	118.75	238	63.25	238	Oct-25	958	Oct-85
239	119.25	239	63.75	239	Nov-25	959	Nov-85
240	119.75	240	64.25	240	Dec-25	960	Dec-85
241	120.25	241	64.75	241	Jan-26	961	Jan-86
242	120.75	242	65.25	242	Feb-26	962	Feb-86
243	121.25	243	65.75	243	Mar-26	963	Mar-86
244	121.75	244	66.25	244	Apr-26	964	Apr-86
245	122.25	245	66.75	245	May-26	965	May-86
246	122.75	246	67.25	246	Jun-26	966	Jun-86
247	123.25	247	67.75	247	Jul-26	967	Jul-86
248	123.75	248	68.25	248	Aug-26	968	Aug-86
249	124.25	249	68.75	249	Sep-26	969	Sep-86
250	124.75	250	69.25	250	Oct-26	970	Oct-86
251	125.25	251	69.75	251	Nov-26	971	Nov-86
252	125.75	252	70.25	252	Dec-26	972	Dec-86
253	126.25	253	70.75	253	Jan-27	973	Jan-87
254	126.75	254	71.25	254	Feb-27	974	Feb-87
255	127.25	255	71.75	255	Mar-27	975	Mar-87
256	127.75	256	72.25	256	Apr-27	976	Apr-87
257	128.25	257	72.75	257	May-27	977	May-87
258	128.75	258	73.25	258	Jun-27	978	Jun-87
259	129.25	259	73.75	259	Jul-27	979	Jul-87
260	129.75	260	74.25	260	Aug-27	980	Aug-87
261	130.25	261	74.75	261	Sep-27	981	Sep-87
262	130.75	262	75.25	262	Oct-27	982	Oct-87
263	131.25	263	75.75	263	Nov-27	983	Nov-87
264	131.75	264	76.25	264	Dec-27	984	Dec-87
265	132.25	265	76.75	265	Jan-28	985	Jan-88
266	132.75	266	77.25	266	Feb-28	986	Feb-88
267	133.25	267	77.75	267	Mar-28	987	Mar-88
268	133.75	268	78.25	268	Apr-28	988	Apr-88
269	134.25	269	78.75	269	May-28	989	May-88
270	134.75	270	79.25	270	Jun-28	990	Jun-88
271	135.25	271	79.75	271	Jul-28	991	Jul-88

Longitude Grid Box #	Longitude in ˚	Latitude Grid Box #	Latitude in ˚	Time Grid Box #	Month & Year	Time Grid Box #	Month & Year
272	135.75	272	80.25	272	Aug-28	992	Aug-88
273	136.25	273	80.75	273	Sep-28	993	Sep-88
274	136.75	274	81.25	274	Oct-28	994	Oct-88
275	137.25	275	81.75	275	Nov-28	995	Nov-88
276	137.75	276	82.25	276	Dec-28	996	Dec-88
277	138.25	277	82.75	277	Jan-29	997	Jan-89
278	138.75	278	83.25	278	Feb-29	998	Feb-89
279	139.25			279	Mar-29	999	Mar-89
280	139.75			280	Apr-29	1000	Apr-89
281	140.25			281	May-29	1001	May-89
282	140.75			282	Jun-29	1002	Jun-89
283	141.25			283	Jul-29	1003	Jul-89
284	141.75			284	Aug-29	1004	Aug-89
285	142.25			285	Sep-29	1005	Sep-89
286	142.75			286	Oct-29	1006	Oct-89
287	143.25			287	Nov-29	1007	Nov-89
288	143.75			288	Dec-29	1008	Dec-89
289	144.25			289	Jan-30	1009	Jan-90
290	144.75			290	Feb-30	1010	Feb-90
291	145.25			291	Mar-30	1011	Mar-90
292	145.75			292	Apr-30	1012	Apr-90
293	146.25			293	May-30	1013	May-90
294	146.75			294	Jun-30	1014	Jun-90
295	147.25			295	Jul-30	1015	Jul-90
296	147.75			296	Aug-30	1016	Aug-90
297	148.25			297	Sep-30	1017	Sep-90
298	148.75			298	Oct-30	1018	Oct-90
299	149.25			299	Nov-30	1019	Nov-90
300	149.75			300	Dec-30	1020	Dec-90
301	150.25			301	Jan-31	1021	Jan-91
302	150.75			302	Feb-31	1022	Feb-91
303	151.25			303	Mar-31	1023	Mar-91
304	151.75			304	Apr-31	1024	Apr-91
305	152.25			305	May-31	1025	May-91
306	152.75			306	Jun-31	1026	Jun-91
307	153.25			307	Jul-31	1027	Jul-91
308	153.75			308	Aug-31	1028	Aug-91
309	154.25			309	Sep-31	1029	Sep-91
310	154.75			310	Oct-31	1030	Oct-91
311	155.25			311	Nov-31	1031	Nov-91

Longitude Grid Box #	Longitude in °	Latitude Grid Box #	Latitude in °	Time Grid Box #	Month & Year	Time Grid Box #	Month & Year
312	155.75			312	Dec-31	1032	Dec-91
313	156.25			313	Jan-32	1033	Jan-92
314	156.75			314	Feb-32	1034	Feb-92
315	157.25			315	Mar-32	1035	Mar-92
316	157.75			316	Apr-32	1036	Apr-92
317	158.25			317	May-32	1037	May-92
318	158.75			318	Jun-32	1038	Jun-92
319	159.25			319	Jul-32	1039	Jul-92
320	159.75			320	Aug-32	1040	Aug-92
321	160.25			321	Sep-32	1041	Sep-92
322	160.75			322	Oct-32	1042	Oct-92
323	161.25			323	Nov-32	1043	Nov-92
324	161.75			324	Dec-32	1044	Dec-92
325	162.25			325	Jan-33	1045	Jan-93
326	162.75			326	Feb-33	1046	Feb-93
327	163.25			327	Mar-33	1047	Mar-93
328	163.75			328	Apr-33	1048	Apr-93
329	164.25			329	May-33	1049	May-93
330	164.75			330	Jun-33	1050	Jun-93
331	165.25			331	Jul-33	1051	Jul-93
332	165.75			332	Aug-33	1052	Aug-93
333	166.25			333	Sep-33	1053	Sep-93
334	166.75			334	Oct-33	1054	Oct-93
335	167.25			335	Nov-33	1055	Nov-93
336	167.75			336	Dec-33	1056	Dec-93
337	168.25			337	Jan-34	1057	Jan-94
338	168.75			338	Feb-34	1058	Feb-94
339	169.25			339	Mar-34	1059	Mar-94
340	169.75			340	Apr-34	1060	Apr-94
341	170.25			341	May-34	1061	May-94
342	170.75			342	Jun-34	1062	Jun-94
343	171.25			343	Jul-34	1063	Jul-94
344	171.75			344	Aug-34	1064	Aug-94
345	172.25			345	Sep-34	1065	Sep-94
346	172.75			346	Oct-34	1066	Oct-94
347	173.25			347	Nov-34	1067	Nov-94
348	173.75			348	Dec-34	1068	Dec-94
349	174.25			349	Jan-35	1069	Jan-95
350	174.75			350	Feb-35	1070	Feb-95
351	175.25			351	Mar-35	1071	Mar-95

Longitude Grid Box #	Longitude in ˚	Latitude Grid Box #	Latitude in ˚	Time Grid Box #	Month & Year	Time Grid Box #	Month & Year
352	175.75			352	Apr-35	1072	Apr-95
353	176.25			353	May-35	1073	May-95
354	176.75			354	Jun-35	1074	Jun-95
355	177.25			355	Jul-35	1075	Jul-95
356	177.75			356	Aug-35	1076	Aug-95
357	178.25			357	Sep-35	1077	Sep-95
358	178.75			358	Oct-35	1078	Oct-95
359	179.25			359	Nov-35	1079	Nov-95
360	179.75			360	Dec-35	1080	Dec-95
361	-179.75			361	Jan-36	1081	Jan-96
362	-179.25			362	Feb-36	1082	Feb-96
363	-178.75			363	Mar-36	1083	Mar-96
364	-178.25			364	Apr-36	1084	Apr-96
365	-177.75			365	May-36	1085	May-96
366	-177.25			366	Jun-36	1086	Jun-96
367	-176.75			367	Jul-36	1087	Jul-96
368	-176.25			368	Aug-36	1088	Aug-96
369	-175.75			369	Sep-36	1089	Sep-96
370	-175.25			370	Oct-36	1090	Oct-96
371	-174.75			371	Nov-36	1091	Nov-96
372	-174.25			372	Dec-36	1092	Dec-96
373	-173.75			373	Jan-37	1093	Jan-97
374	-173.25			374	Feb-37	1094	Feb-97
375	-172.75			375	Mar-37	1095	Mar-97
376	-172.25			376	Apr-37	1096	Apr-97
377	-171.75			377	May-37	1097	May-97
378	-171.25			378	Jun-37	1098	Jun-97
379	-170.75			379	Jul-37	1099	Jul-97
380	-170.25			380	Aug-37	1100	Aug-97
381	-169.75			381	Sep-37	1101	Sep-97
382	-169.25			382	Oct-37	1102	Oct-97
383	-168.75			383	Nov-37	1103	Nov-97
384	-168.25			384	Dec-37	1104	Dec-97
385	-167.75			385	Jan-38	1105	Jan-98
386	-167.25			386	Feb-38	1106	Feb-98
387	-166.75			387	Mar-38	1107	Mar-98
388	-166.25			388	Apr-38	1108	Apr-98
389	-165.75			389	May-38	1109	May-98
390	-165.25			390	Jun-38	1110	Jun-98
391	-164.75			391	Jul-38	1111	Jul-98

Longitude Grid Box #	Longitude in ˚	Latitude Grid Box #	Latitude in ˚	Time Grid Box #	Month & Year	Time Grid Box #	Month & Year
392	-164.25			392	Aug-38	1112	Aug-98
393	-163.75			393	Sep-38	1113	Sep-98
394	-163.25			394	Oct-38	1114	Oct-98
395	-162.75			395	Nov-38	1115	Nov-98
396	-162.25			396	Dec-38	1116	Dec-98
397	-161.75			397	Jan-39	1117	Jan-99
398	-161.25			398	Feb-39	1118	Feb-99
399	-160.75			399	Mar-39	1119	Mar-99
400	-160.25			400	Apr-39	1120	Apr-99
401	-159.75			401	May-39	1121	May-99
402	-159.25			402	Jun-39	1122	Jun-99
403	-158.75			403	Jul-39	1123	Jul-99
404	-158.25			404	Aug-39	1124	Aug-99
405	-157.75			405	Sep-39	1125	Sep-99
406	-157.25			406	Oct-39	1126	Oct-99
407	-156.75			407	Nov-39	1127	Nov-99
408	-156.25			408	Dec-39	1128	Dec-99
409	-155.75			409	Jan-40	1129	Jan-00
410	-155.25			410	Feb-40	1130	Feb-00
411	-154.75			411	Mar-40	1131	Mar-00
412	-154.25			412	Apr-40	1132	Apr-00
413	-153.75			413	May-40	1133	May-00
414	-153.25			414	Jun-40	1134	Jun-00
415	-152.75			415	Jul-40	1135	Jul-00
416	-152.25			416	Aug-40	1136	Aug-00
417	-151.75			417	Sep-40	1137	Sep-00
418	-151.25			418	Oct-40	1138	Oct-00
419	-150.75			419	Nov-40	1139	Nov-00
420	-150.25			420	Dec-40	1140	Dec-00
421	-149.75			421	Jan-41		
422	-149.25			422	Feb-41		
423	-148.75			423	Mar-41		
424	-148.25			424	Apr-41		
425	-147.75			425	May-41		
426	-147.25			426	Jun-41		
427	-146.75			427	Jul-41		
428	-146.25			428	Aug-41		
429	-145.75			429	Sep-41		
430	-145.25			430	Oct-41		
431	-144.75			431	Nov-41		

Longitude Grid Box #	Longitude in ˚	Latitude Grid Box #	Latitude in ˚	Time Grid Box #	Month & Year	Time Grid Box #	Month & Year
432	-144.25			432	Dec-41		
433	-143.75			433	Jan-42		
434	-143.25			434	Feb-42		
435	-142.75			435	Mar-42		
436	-142.25			436	Apr-42		
437	-141.75			437	May-42		
438	-141.25			438	Jun-42		
439	-140.75			439	Jul-42		
440	-140.25			440	Aug-42		
441	-139.75			441	Sep-42		
442	-139.25			442	Oct-42		
443	-138.75			443	Nov-42		
444	-138.25			444	Dec-42		
445	-137.75			445	Jan-43		
446	-137.25			446	Feb-43		
447	-136.75			447	Mar-43		
448	-136.25			448	Apr-43		
449	-135.75			449	May-43		
450	-135.25			450	Jun-43		
451	-134.75			451	Jul-43		
452	-134.25			452	Aug-43		
453	-133.75			453	Sep-43		
454	-133.25			454	Oct-43		
455	-132.75			455	Nov-43		
456	-132.25			456	Dec-43		
457	-131.75			457	Jan-44		
458	-131.25			458	Feb-44		
459	-130.75			459	Mar-44		
460	-130.25			460	Apr-44		
461	-129.75			461	May-44		
462	-129.25			462	Jun-44		
463	-128.75			463	Jul-44		
464	-128.25			464	Aug-44		
465	-127.75			465	Sep-44		
466	-127.25			466	Oct-44		
467	-126.75			467	Nov-44		
468	-126.25			468	Dec-44		
469	-125.75			469	Jan-45		
470	-125.25			470	Feb-45		
471	-124.75			471	Mar-45		

Longitude Grid Box #	Longitude in ˚	Latitude Grid Box #	Latitude in ˚	Time Grid Box #	Month & Year	Time Grid Box #	Month & Year
472	-124.25			472	Apr-45		
473	-123.75			473	May-45		
474	-123.25			474	Jun-45		
475	-122.75			475	Jul-45		
476	-122.25			476	Aug-45		
477	-121.75			477	Sep-45		
478	-121.25			478	Oct-45		
479	-120.75			479	Nov-45		
480	-120.25			480	Dec-45		
481	-119.75			481	Jan-46		
482	-119.25			482	Feb-46		
483	-118.75			483	Mar-46		
484	-118.25			484	Apr-46		
485	-117.75			485	May-46		
486	-117.25			486	Jun-46		
487	-116.75			487	Jul-46		
488	-116.25			488	Aug-46		
489	-115.75			489	Sep-46		
490	-115.25			490	Oct-46		
491	-114.75			491	Nov-46		
492	-114.25			492	Dec-46		
493	-113.75			493	Jan-47		
494	-113.25			494	Feb-47		
495	-112.75			495	Mar-47		
496	-112.25			496	Apr-47		
497	-111.75			497	May-47		
498	-111.25			498	Jun-47		
499	-110.75			499	Jul-47		
500	-110.25			500	Aug-47		
501	-109.75			501	Sep-47		
502	-109.25			502	Oct-47		
503	-108.75			503	Nov-47		
504	-108.25			504	Dec-47		
505	-107.75			505	Jan-48		
506	-107.25			506	Feb-48		
507	-106.75			507	Mar-48		
508	-106.25			508	Apr-48		
509	-105.75			509	May-48		
510	-105.25			510	Jun-48		
511	-104.75			511	Jul-48		

Longitude Grid Box #	Longitude in ˚	Latitude Grid Box #	Latitude in ˚	Time Grid Box #	Month & Year	Time Grid Box #	Month & Year
512	-104.25			512	Aug-48		
513	-103.75			513	Sep-48		
514	-103.25			514	Oct-48		
515	-102.75			515	Nov-48		
516	-102.25			516	Dec-48		
517	-101.75			517	Jan-49		
518	-101.25			518	Feb-49		
519	-100.75			519	Mar-49		
520	-100.25			520	Apr-49		
521	-99.75			521	May-49		
522	-99.25			522	Jun-49		
523	-98.75			523	Jul-49		
524	-98.25			524	Aug-49		
525	-97.75			525	Sep-49		
526	-97.25			526	Oct-49		
527	-96.75			527	Nov-49		
528	-96.25			528	Dec-49		
529	-95.75			529	Jan-50		
530	-95.25			530	Feb-50		
531	-94.75			531	Mar-50		
532	-94.25			532	Apr-50		
533	-93.75			533	May-50		
534	-93.25			534	Jun-50		
535	-92.75			535	Jul-50		
536	-92.25			536	Aug-50		
537	-91.75			537	Sep-50		
538	-91.25			538	Oct-50		
539	-90.75			539	Nov-50		
540	-90.25			540	Dec-50		
541	-89.75			541	Jan-51		
542	-89.25			542	Feb-51		
543	-88.75			543	Mar-51		
544	-88.25			544	Apr-51		
545	-87.75			545	May-51		
546	-87.25			546	Jun-51		
547	-86.75			547	Jul-51		
548	-86.25			548	Aug-51		
549	-85.75			549	Sep-51		
550	-85.25			550	Oct-51		
551	-84.75			551	Nov-51		

Longitude Grid Box #	Longitude in ˚	Latitude Grid Box #	Latitude in ˚	Time Grid Box #	Month & Year	Time Grid Box #	Month & Year
552	-84.25			552	Dec-51		
553	-83.75			553	Jan-52		
554	-83.25			554	Feb-52		
555	-82.75			555	Mar-52		
556	-82.25			556	Apr-52		
557	-81.75			557	May-52		
558	-81.25			558	Jun-52		
559	-80.75			559	Jul-52		
560	-80.25			560	Aug-52		
561	-79.75			561	Sep-52		
562	-79.25			562	Oct-52		
563	-78.75			563	Nov-52		
564	-78.25			564	Dec-52		
565	-77.75			565	Jan-53		
566	-77.25			566	Feb-53		
567	-76.75			567	Mar-53		
568	-76.25			568	Apr-53		
569	-75.75			569	May-53		
570	-75.25			570	Jun-53		
571	-74.75			571	Jul-53		
572	-74.25			572	Aug-53		
573	-73.75			573	Sep-53		
574	-73.25			574	Oct-53		
575	-72.75			575	Nov-53		
576	-72.25			576	Dec-53		
577	-71.75			577	Jan-54		
578	-71.25			578	Feb-54		
579	-70.75			579	Mar-54		
580	-70.25			580	Apr-54		
581	-69.75			581	May-54		
582	-69.25			582	Jun-54		
583	-68.75			583	Jul-54		
584	-68.25			584	Aug-54		
585	-67.75			585	Sep-54		
586	-67.25			586	Oct-54		
587	-66.75			587	Nov-54		
588	-66.25			588	Dec-54		
589	-65.75			589	Jan-55		
590	-65.25			590	Feb-55		
591	-64.75			591	Mar-55		

Longitude Grid Box #	Longitude in ˚	Latitude Grid Box #	Latitude in ˚	Time Grid Box #	Month & Year	Time Grid Box #	Month & Year
592	-64.25			592	Apr-55		
593	-63.75			593	May-55		
594	-63.25			594	Jun-55		
595	-62.75			595	Jul-55		
596	-62.25			596	Aug-55		
597	-61.75			597	Sep-55		
598	-61.25			598	Oct-55		
599	-60.75			599	Nov-55		
600	-60.25			600	Dec-55		
601	-59.75			601	Jan-56		
602	-59.25			602	Feb-56		
603	-58.75			603	Mar-56		
604	-58.25			604	Apr-56		
605	-57.75			605	May-56		
606	-57.25			606	Jun-56		
607	-56.75			607	Jul-56		
608	-56.25			608	Aug-56		
609	-55.75			609	Sep-56		
610	-55.25			610	Oct-56		
611	-54.75			611	Nov-56		
612	-54.25			612	Dec-56		
613	-53.75			613	Jan-57		
614	-53.25			614	Feb-57		
615	-52.75			615	Mar-57		
616	-52.25			616	Apr-57		
617	-51.75			617	May-57		
618	-51.25			618	Jun-57		
619	-50.75			619	Jul-57		
620	-50.25			620	Aug-57		
621	-49.75			621	Sep-57		
622	-49.25			622	Oct-57		
623	-48.75			623	Nov-57		
624	-48.25			624	Dec-57		
625	-47.75			625	Jan-58		
626	-47.25			626	Feb-58		
627	-46.75			627	Mar-58		
628	-46.25			628	Apr-58		
629	-45.75			629	May-58		
630	-45.25			630	Jun-58		
631	-44.75			631	Jul-58		

Longitude Grid Box #	Longitude in ˚	Latitude Grid Box #	Latitude in ˚	Time Grid Box #	Month & Year	Time Grid Box #	Month & Year
632	-44.25			632	Aug-58		
633	-43.75			633	Sep-58		
634	-43.25			634	Oct-58		
635	-42.75			635	Nov-58		
636	-42.25			636	Dec-58		
637	-41.75			637	Jan-59		
638	-41.25			638	Feb-59		
639	-40.75			639	Mar-59		
640	-40.25			640	Apr-59		
641	-39.75			641	May-59		
642	-39.25			642	Jun-59		
643	-38.75			643	Jul-59		
644	-38.25			644	Aug-59		
645	-37.75			645	Sep-59		
646	-37.25			646	Oct-59		
647	-36.75			647	Nov-59		
648	-36.25			648	Dec-59		
649	-35.75			649	Jan-60		
650	-35.25			650	Feb-60		
651	-34.75			651	Mar-60		
652	-34.25			652	Apr-60		
653	-33.75			653	May-60		
654	-33.25			654	Jun-60		
655	-32.75			655	Jul-60		
656	-32.25			656	Aug-60		
657	-31.75			657	Sep-60		
658	-31.25			658	Oct-60		
659	-30.75			659	Nov-60		
660	-30.25			660	Dec-60		
661	-29.75			661	Jan-61		
662	-29.25			662	Feb-61		
663	-28.75			663	Mar-61		
664	-28.25			664	Apr-61		
665	-27.75			665	May-61		
666	-27.25			666	Jun-61		
667	-26.75			667	Jul-61		
668	-26.25			668	Aug-61		
669	-25.75			669	Sep-61		
670	-25.25			670	Oct-61		
671	-24.75			671	Nov-61		

Longitude Grid Box #	Longitude in ˚	Latitude Grid Box #	Latitude in ˚	Time Grid Box #	Month & Year	Time Grid Box #	Month & Year
672	-24.25			672	Dec-61		
673	-23.75			673	Jan-62		
674	-23.25			674	Feb-62		
675	-22.75			675	Mar-62		
676	-22.25			676	Apr-62		
677	-21.75			677	May-62		
678	-21.25			678	Jun-62		
679	-20.75			679	Jul-62		
680	-20.25			680	Aug-62		
681	-19.75			681	Sep-62		
682	-19.25			682	Oct-62		
683	-18.75			683	Nov-62		
684	-18.25			684	Dec-62		
685	-17.75			685	Jan-63		
686	-17.25			686	Feb-63		
687	-16.75			687	Mar-63		
688	-16.25			688	Apr-63		
689	-15.75			689	May-63		
690	-15.25			690	Jun-63		
691	-14.75			691	Jul-63		
692	-14.25			692	Aug-63		
693	-13.75			693	Sep-63		
694	-13.25			694	Oct-63		
695	-12.75			695	Nov-63		
696	-12.25			696	Dec-63		
697	-11.75			697	Jan-64		
698	-11.25			698	Feb-64		
699	-10.75			699	Mar-64		
700	-10.25			700	Apr-64		
701	-9.75			701	May-64		
702	-9.25			702	Jun-64		
703	-8.75			703	Jul-64		
704	-8.25			704	Aug-64		
705	-7.75			705	Sep-64		
706	-7.25			706	Oct-64		
707	-6.75			707	Nov-64		
708	-6.25			708	Dec-64		
709	-5.75			709	Jan-65		
710	-5.25			710	Feb-65		
711	-4.75			711	Mar-65		

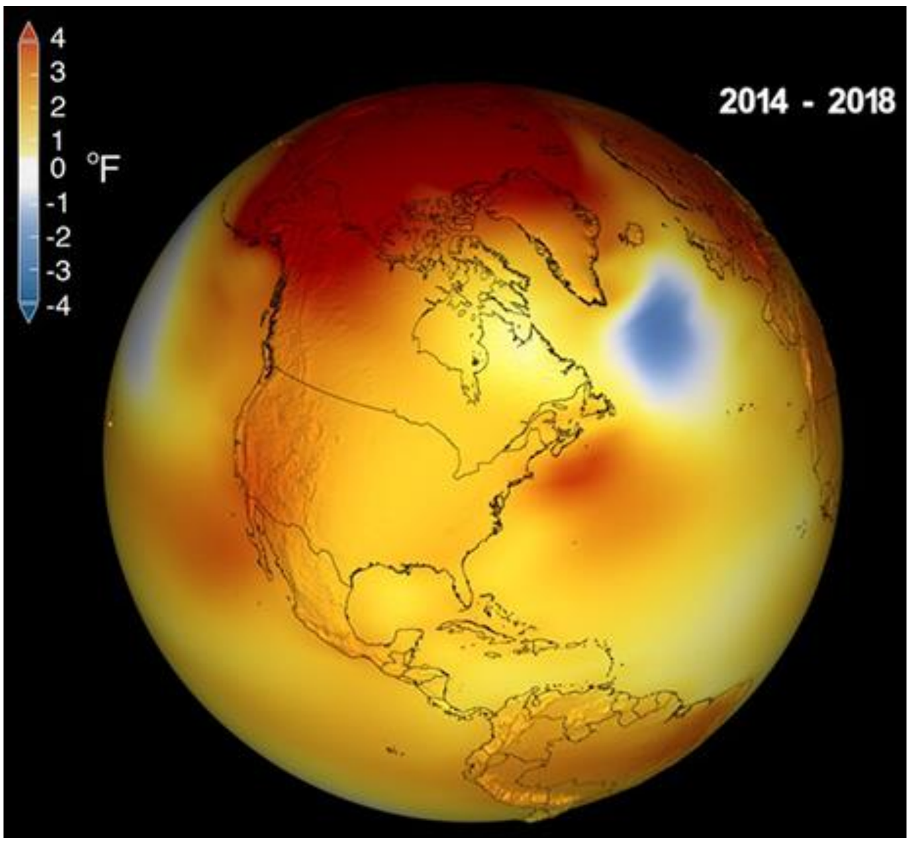
Longitude Grid Box #	Longitude in ˚	Latitude Grid Box #	Latitude in ˚	Time Grid Box #	Month & Year	Time Grid Box #	Month & Year
712	-4.25			712	Apr-65		
713	-3.75			713	May-65		
714	-3.25			714	Jun-65		
715	-2.75			715	Jul-65		
716	-2.25			716	Aug-65		
717	-1.75			717	Sep-65		
718	-1.25			718	Oct-65		
719	-0.75			719	Nov-65		
720	-0.25			720	Dec-65		

E. Conclusion and overview of linkages to next lesson and unit goals

In this lesson, the students learned how to write a script in RStudio that reads in the netCDF future projection model output from the GISS ModelE2 and extracts data for a specific location, New York City. The students also learned how to subtract model output to calculate the results of the RCP 4.5 – 2.6 and RCP 8.5 – 2.6 scenarios and how to separate the output into three different 30-year intervals from 2011 to 2100. The students were then able to calculate future average monthly temperature projections and create two triple-line graphs to show the average monthly changes in temperature projections for the RCP 4.5 – 2.6 and RCP 8.5 – 2.6 scenarios overtime. The goal of this lesson was not only for the students to learn how temperature projections are expected to differ based on the RCP scenario and the month of the year, but also for the students to learn the necessary skills for analyzing netCDF data in RStudio. The students will use their knowledge from this lesson as they head into the last lesson of the unit where they will write a code to conduct similar analyses for different cities around the world.

NASA Goddard Institute for Space Studies (GISS)
Climate Change Research Initiative (CCRI)
Applied Research STEM Curriculum Unit Portfolio

Unit Title: Future Temperature Projections
Lesson #3 Title: Using RStudio: Creating Temperature Projection Graphs for Cities Around the World
NASA STEM Educator / Associate Researcher: Nicole Dulaney
NASA PI / Mentor: Dr. Allegra N. LeGrande
NASA GSFC Office of Education – Code 160



IX. Lesson #3: Using RStudio: Creating Temperature Projection Graphs for Cities Around the World

A. Summary and Goals of Lesson

In this lesson, the students will use their knowledge of RStudio from the previous lesson to analyze future monthly temperature projections for the RCP 4.5 – 2.6 and RCP 8.5 – 2.6 scenarios for different cities around the world. The students will be working in groups and assigned a city that is influenced by a large-scale climate factor such as proximity to the water, latitude, and influence of the Indian Monsoon, the Intertropical Convergence Zone (ITCZ), El Niño Southern Oscillation, and the North Atlantic Oscillation. Once the students create graphs using RStudio, they will work with their group members to prepare an oral presentation about the climate of their city and the expected impacts of climate change. The goal is for the students to learn how climate change is expected to impact all regions of the world differently.

This lesson includes a Teacher Information guide to help teachers navigate the climate-related details of the cities that are recommended for the students to explore. Of course, teachers are welcome to choose their own cities! The lesson also includes a rubric that is recommended for assessment of student oral presentations.

B. Table of Contents for lesson

National Aeronautics and Space Administration
Goddard Institute for Space Studies
New York, N.Y.

C. 5 E Lesson Model Template

Teachers, please review the Teacher Information sheet available after the lesson plan prior to allowing students to complete this lesson.

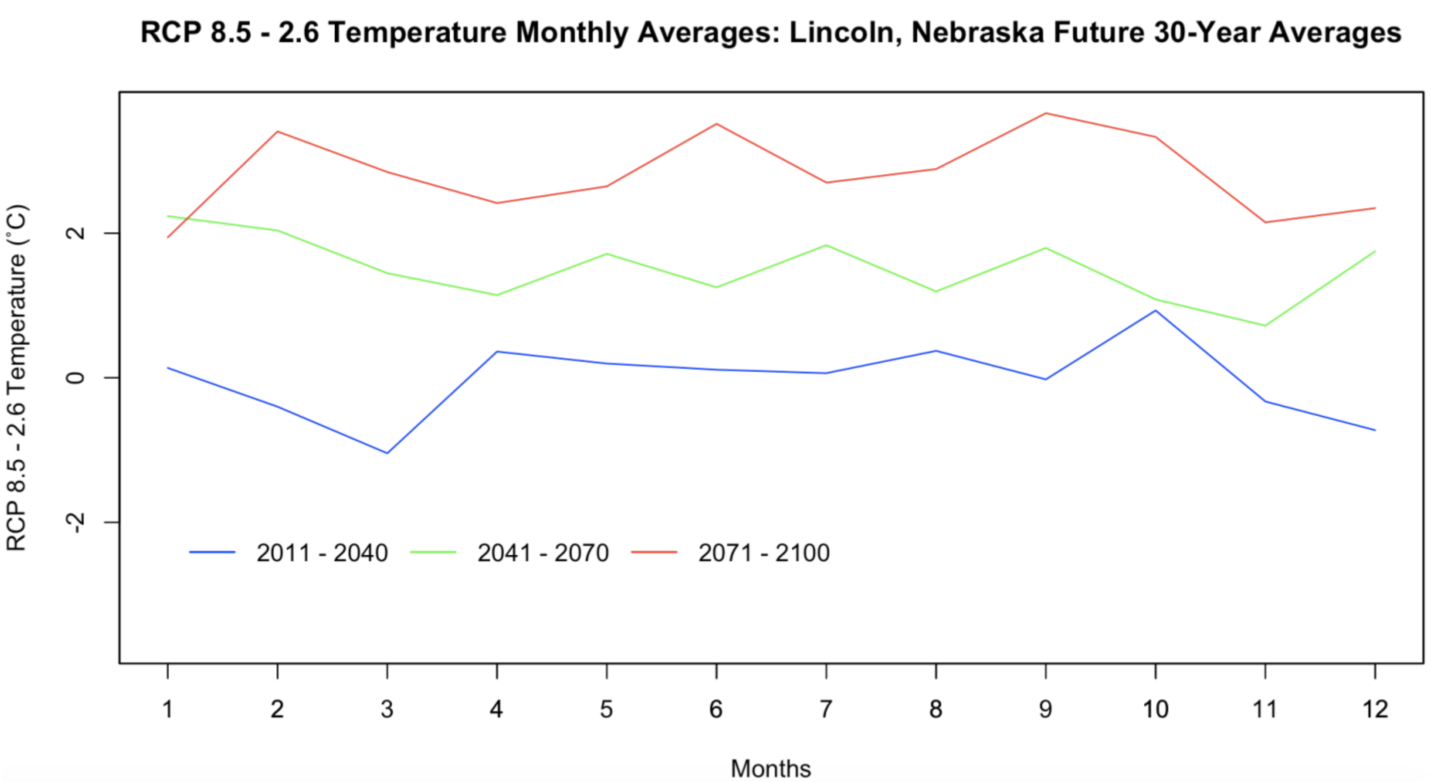
STEM Earth Science Research

Unit: Future Temperature Projections **Topic**: Creating Temperature Projection Graphs for Cities Around the World

Prior Learning: For successful completion of this lesson, the students should have knowledge of the RCP 4.5 – 2.6 and RCP 8.5 – 2.6 temperature projection scenarios from Lessons #1 and #2 of this unit. Students should also have the skills from Lesson #2 needed to create plots using netCDF output in RStudio. In this lesson, the students are going to use RStudio to create the two plots similar to those they analyzed in the last lesson for another city around the world. The students will then prepare and deliver an oral presentation about future climate change in their city.

Warm Up Activity:

1. Based on the graph provided, what general conclusions can we make about temperature projections for the RCP 8.5 – 2.6 scenario in Lincoln, Nebraska.



Aim: How can we evaluate future temperature projections for cities around the world?

<u>New York State Standards</u>:

1.1f - Earth's changing position with regard to the Sun and the moon has noticeable effects.

- Earth revolves around the Sun with its rotational axis tilted at 23.5 degrees to a line perpendicular to the plane of its orbit, with the North Pole aligned with Polaris.
- During Earth's one-year period of revolution, the tilt of its axis results in changes in the angle of incidence of the Sun's rays at a given latitude; these changes cause variation in the heating of the surface. This produces seasonal variation in weather.

2.2a - Insolation (solar radiation) heats Earth's surface and atmosphere unequally due to variations in:

- the intensity caused by differences in atmospheric transparency and angle of incidence which vary with time of day, latitude, and season
- characteristics of the materials absorbing the energy such as color, texture, transparency, state of matter, and specific heat
- duration, which varies with seasons and latitude.

<u>Next Generation Science Standards</u>:

HS - ESS2-4 - Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate.

HS - ESS3-5 - Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth systems.

<u>Common Core State Standards</u>:

CCSS: 9-10.RST.3 - Follow precisely a multistep procedure when carrying out experiments, taking measurements, or performing technical tasks.

CCSS: 9-10.RST.7 - Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem.

<u>NASA System Engineering Behavior</u>:

Technical Acumen:

1. (a) Possesses Technical Competence and Has Comprehensive Previous Experience
   (b) Learns from Successes and Failures

Problem Solving & Systems Thinking:

2. (a) Thinks Systematically
   (b) Possess Creativity and Problem-Solving Abilities

<u>Performance Objective:</u> Students will be able to evaluate how climate change will impact other cities around the world by using RStudio to create average monthly temperature projection plots using the RCP difference scenarios.

Students will also be able to evaluate how climate change will impact other cities around the world by creating and delivering an oral presentation about future climate change in their city.

Materials: GISS ModelE2 Projection output; Rstudio; Class set of computers; Microsoft PowerPoint or Google Slides
Links to electronic sources are provided below:

- GISS ModelE2 Projection Simulations: ftp://gdo-dcp.ucllnl.org/pub/dcp/archive/cmip5/global_mon/BCSD/giss-e2-r/
  - The link above cannot be a descriptive link because it must be copied and pasted exactly as is into a browser.
- Link to RStudio program download
- Link to the NASA climate website for information about causes, effects, and solutions

Vocabulary: No new vocabulary.

Anticipatory Opening: After the Warm Up Activity, have the students discuss their answers with a partner and then transition to a whole class discussion to see how the students envision climate change impacting cities other than New York City.

Development of the Lesson: Approximate 8-Day lesson (eight 50-minute periods) including the oral presentations. This can differ depending on class size and the number of groups.

What the teacher does	What the student does	Time
1. Write down the Warm Up Activity, Aim, and the HW on the blackboard.		
2. ENGAGE Circulate the room while the students complete the Warm Up Activity question about an average monthly temperature projection graph for Lincoln, Nebraska. The purpose of this Warm Up Activity question is to ensure students know how to properly draw conclusions from these graphs. After the students submit their Warm Up Activity through Google Classroom, we will discuss as a class the components of a model answer. A class comment on Google Classroom with the model answer will then be shared. ***Assessment Opportunity #1 (Student answer to the Warm Up Activity.)***	The students answer the Warm Up Activity question by analyzing an average monthly temperature projection graph for Lincoln, Nebraska. The students view the model answer on Google Classroom or a similar platform so they know what the teacher is looking for in their future analyses.	**15 min**
4. EXPLORE & EXPLAIN Introduce the activity to the students. Students are working in groups and are assigned specific cities around the world to analyze. Suggested cities for the students to explore are listed on a **Teacher Information** document found after the lesson plan.	The students are assigned a group and a specific city to analyze. The students begin working on the Using RStudio: Creating Temperature Projection Graphs for Cities Around the World activity.	**Two class periods**

What the teacher does	What the student does	Time
Circulate the room as the students complete the Using RStudio: Creating Temperature Projection Graphs for Cities Around the World activity. Look for common challenges and misconceptions in the activity. Specifically, ensure the students are finding latitude and longitude coordinates for locations over land; locations over water will have NA values. ***Assessment Opportunity #2 (Student discussions about the RStudio activity).*** ***Assessment Opportunity #3 (Student-created graphs in RStudio).***	The students use RStudio to create two average monthly temperature projection graphs with the three 30-year intervals for both the RCP 8.5 – 2.6 and RCP 4.5 – 2.6 scenarios.	
5. ELABORATE & EVALUATE Have the students transition to creating their oral presentation using either Microsoft PowerPoint or Google Slides. Go over the rubric with the students to ensure all students are aware how they will be assessed. Circulate the room as the students work on their oral presentations. Ensure the students are using appropriate font sizes/color schemes and that they are including all necessary components. If students need help understanding the effects of climate change and mitigation strategies, direct them to this link to the NASA climate website. Teachers can also direct students to the resources provided on the **Teacher Information** document. ***Assessment Opportunity #4 (Student-created oral presentations).***	The students create an oral presentation based on the guidelines and rubric outlined in steps #4 & #5 of the activity. The students review the oral presentation rubric and ask any questions they have about how they will be assessed. The students will sign up to deliver the oral presentations over the next few class days. If students need help understanding the effects of climate change and mitigation strategies, direct them to this link to the NASA climate website .	**4 periods**
6. Use the attached rubric to assess student oral presentations. There are three presentations a day, each no more than 15-minutes in length. Explain to the students how they will be giving peer feedback using the Glow & Grow protocol. ***Assessment Opportunity #5 (Student oral presentations).***	The students present their oral presentations to the class. The students provide peer feedback using the Glow & Grow protocol.	**2 periods (or more depending on class size)**

Summary/Conclusion: The students present their oral presentations to the class. The students provide peer feedback using the Glow & Grow protocol.

Differentiated Instruction:

- The students are exposed to content in written, oral, and visual forms (multiple modalities exist).
- Students are asked both higher and lower level questions so all students can answer questions at their particular academic level.
- Students are given time to answer questions during think pair share/group activities.
- Students who need extra support can join the teacher for small group instruction and more efficient feedback.
- Students who are performing at a higher level can complete the tasks provided in the For Further Exploration part of the lesson plan.
- Since students will be working in groups, there are enough roles available for each student to effectively contribute to the group's success regardless of skill level. Roles can include creating the graphs in RStudio, designing the presentation, researching climate change mitigation strategies, etc.

For Further Exploration: Use the RScripts from this lesson to specify different latitude and longitude coordinates to explore to see how climate change will impact different cities on Earth.

Notes For Revision:

D. Supporting Documents (order according to sequence of lesson)

Name: ____ Date: ______________

Teacher Information

Using RStudio: Creating Temperature Projections for Cities Around the World

Activity Description: The purpose of this activity is for the students to use the skills gained in the previous lesson titled Using RStudio: Creating Temperature Projection Graphs for New York City to create average monthly temperature projection plots for another city around the world. Once the students create their plots, they will prepare an oral presentation using Microsoft PowerPoint or Google Slides to teach the class how their city is expected to be impacted by climate change based on the RCP projection simulations from the GISS ModelE2.

NOTE: The lesson titled **Using RStudio: Creating Temperature Projection Graphs for New York City** needs to be completed prior to this activity. Teachers and students need to have all of the RCP 2.6, 4.5, and 8.5 temperature model output already downloaded onto the computer.

Global City Options:

The cities provided below were each chosen for specific reasons explained next to each city. These cities are only a suggestion and can be substituted for others. Students should be working in groups and each group should be assigned a specific city.

- **Kuala Lumpur, Malaysia**
  - This city is located in the Maritime Continent and is close to the equator. This city receives a high angle of insolation throughout the entire year, resulting in little variation in temperature from month to month. This city is also influenced seasonally by the Intertropical Convergence Zone (ITCZ), resulting in less precipitation in the Northern Hemisphere summer and more in the Northern Hemisphere winter. Additional information about the ITCZ is provided in a resource below.
- **Kozhikode, India**
  - This city experiences a seasonal influence in precipitation due to the Indian Monsoon and the Intertropical Convergence Zone (ITCZ). This city receives significantly more rain in the Northern Hemisphere summer months due to the northward shift of the ITCZ and the changing prevailing wind patterns. Differential heating between land and water ultimately leads to the change in wind patterns and therefore precipitation patterns. Additional information about the ITCZ and monsoons are provided in a resource below.
- **Darwin, Australia**
  - This city's temperature and precipitation patterns can be influenced by the El Niño Southern Oscillation (ENSO). During the warm phase of ENSO, referred to as El Niño, this city can experience less precipitation and warmer temperatures due to less cloud cover. Additional information about ENSO and El Niño can be found below.

- **Houston, Texas**
  - This city is located along the coast of the Gulf of Mexico and is susceptible to extreme precipitation events.
- **London, England**
  - Winter months in this city can be influenced by the North Atlantic Oscillation (NAO). The NAO has a positive and a negative phase. When the NAO is positive, this city and the rest of Central Europe can have warmer and wetter winters. When the NAO is negative, this city can experience colder and drier winters. Additional information about the NAO can be found in a resource below.
- **Las Vegas, Nevada**
  - This city is located in a desert near the west coast of the United States. This city is susceptible to both droughts and heat waves.
- **Manaus, Brazil**
  - This city is located in the rainforest and experiences a high angle of insolation and high amounts of precipitation throughout the year. This city is also under the influence of the Intertropical Convergence Zone (ITCZ) for majority of the year. Additional information on the ITCZ can be found in a resource below.

Resources:

Below are links to resources to further explain the climate parameters and teleconnections that can influence the climate of the cities listed above:

- **Intertropical convergence zone (ITCZ):** Link to ITCZ information from the NASA Earth Observatory
- **North Atlantic Oscillation (NAO)**: Link #1 with information about the North Atlantic Oscillation from the NASA Earth Observatory and
  Link #2 with information about the North Atlantic Oscillation from the NASA Earth Observatory
- **El Niño Southern Oscillation (ENSO)**: Link from NOAA about ENSO and Link from the NASA Earth Observatory about ENSO
- **Indian Monsoon (referred to in resource as South Asian Monsoon)**: Link from NASA about the Indian Monsoon

Challenges:

- Some cities are located close to the ocean. If students use the wrong latitude and longitude coordinates for their city in their code, they could be extracting NA values. There are only values available over land areas in the model output, and any value over water is represented with NA instead of a temperature value. Be sure to circulate often to ensure students are using the correct coordinates.

Name: ____________________________________ Date: _____________

Student Activity
Using RStudio: Creating Temperature Projection Graphs for Cities Around the World

Activity Description: The purpose of this activity is for the students to use the skills gained in the previous lesson titled Using RStudio: Creating Temperature Projection Graphs for New York City to create average monthly temperature projection plots for another city around the world. Once the students create their plots, they will prepare an oral presentation using Microsoft PowerPoint or Google Slides to teach the class how their city is expected to be impacted by climate change based on the RCP projection simulations from the GISS ModelE2.

The city your group will be investigating is ___________________________________.

RStudio Task

Step 1. Open RStudio and open a new R Script by clicking **"File"** at the very top of RStudio, and then click **"New File"**, and then click **R Script.**

Step 2. On line #1 of your R Script, type **library(ncdf4)** and on line #2 type **library(zoo)** to specify the libraries you will need to run your codes in this lesson.

Highlight and run lines #1 & #2 to ensure there are no error messages. If there are error messages, you most likely need to install the libraries again using the **install.packages** command in the **Console**.

On line #3, write code that will source the **Functions.R** script we used in the previous lesson. Look back to your scripts from the previous lesson if necessary.

Step 3. In this lesson you will be working with a group to evaluate temperature projections for your city. You will be using the codes you developed in the previous lesson to help create the following graphs:

- **Graph #1** – Triple line graph showing the average monthly temperature projections for three 30-year intervals for the RCP 4.5 – RCP 2.6 scenario.
- **Graph #2** – Triple line graph showing the average monthly temperature projections for three 30-year intervals for the RCP 8.5 – RCP 2.6 scenario.

Be sure you are using the correct latitude and longitude for your city in the beginning of your code!

Step 4. You will now begin writing a code to create the two graphs specified in step #3 of this activity. Use your codes from the previous lesson titled Using RStudio: Creating Temperature Projection Graphs for New York City as a guide.

Each graph should contain the following:

- Three lines, one representing each 30-year interval. Each line should be a different color.
- A proper label on the x-axis including units.
- A proper label on the y-axis including units.
- A y-axis scale that is centered around 0.
- A proper title to describe the data within the graph, including the location.
- A map legend that specifies the data that is associated with each line color.
- A map legend that fits appropriately in empty space on your graph.

Q2. Insert Graph #1, the triple line graph showing the average monthly temperature projections for three 30-year intervals for the RCP 4.5 – RCP 2.6 scenario.

Q3. Insert Graph #2, the triple line graph showing the average monthly temperature projections for three 30-year intervals for the RCP 8.5 – RCP 2.6 scenario.

5. Once the graphs are created, you will create an oral presentation through Microsoft PowerPoint or Google Slides that should be no more than 15 minutes. Your presentations should include:

- Geographic information about the city you chose, including maps and other images. You should also include information on any geographic features such as oceans, mountains, etc., that can influence the climate of your city.
- A description of the general climate of your city throughout the year. This should include any seasonal changes in climate and the causes for those seasonal changes.
    - You should also discuss if there are any large-scale climate parameters such as ENSO, monsoon, etc., that can influence the climate of your city. This will require research!
- The two graphs you created in RStudio should each have their own slide. Each graph should have a description of the following:
    - How the variable in the graph changed based on the month of the year.
    - The meaning of RCP 4.5 – 2.6 and RCP 8.5 – 2.6 should be explained. For instance, when are the RCP 4.5 & RCP 8.5 scenarios greater or less than the RCP 2.6 scenario?
    - There should be a description of any differences between the three 30-year intervals.
    - **All possible conclusions should be explained for each graph.**
    - All graphs will be evaluated by the components outlined in step #4 of this activity.
- A description of any strategies your city is taking or plans to take to lessen the impacts of climate change. These strategies should be geared towards the biggest climate change-related threats your city is expected to face.

Presentations will be assessed using the following rubric:

Future Climate Change Projections – Oral Presentation Rubric

CATEGORY	4	3	2	1
Geographic Information	Student fully and accurately explains the geographic location of their city, including images to accompany the description.	Student accurately describes the geographic location of their city, but more detail could have been provided to the audience.	Student makes one error when describing the geographic location of their city.	Student makes more than one error when describing the geographic location of their city.
General Climate	Student fully explains the general climate of the city, specifically seasonal changes and the causes for the seasonal changes. Students also include additional information about climate parameters or events that impact the city.	Student explains the general climate of the city, but more detail could have been provided for seasonal changes. Student also could have provided more detail about climate parameters/events.	Student makes one error when describing the general climate OR does not include one piece of required information.	Student makes more than one error when describing the general climate OR does not include more than one piece of required information.
Projection Graphs (Two total)	Student produces both required graphs and each graph has all of the specified components. The audience does not need any clarification as to what each graph is about.	Student displays both required graphs, but there is one error based on the specified components or the audience needs more clarification.	Student displays both required graphs, but there is more than one error based on the specified components.	Student is missing one or more of the required graphs.
Explanation of Graphs	Student fully and accurately describes all of the conclusions both required graphs.	Student accurately describes the conclusions of both required graphs, but more detail could have been provided to the audience.	Student makes one or more error(s) when describing the conclusions of both required graphs.	Student is missing one or more conclusion(s) of the required graphs.

CATEGORY	4	3	2	1
Climate Change Mitigation	Groups fully describe how their city is prepared/will prepare for the impacts of climate change in the future.	Groups describe how their city is prepared/will prepare for the impacts of climate change in the future, but more detail could have been provided.	Groups describe how their city is prepared/will prepare for the impacts of climate change in the future, with one error.	Groups describe how their city is prepared/will prepare for the impacts of climate change in the future, with more than one error.
Volume	Volume is loud enough to be heard by all audience members throughout the presentation.	Volume is loud enough to be heard by all audience members at least 90% of the time.	Volume is loud enough to be heard by all audience members at least 80% of the time.	Volume often too soft to be heard by all audience members.
Speaks Clearly	Speaks clearly and distinctly all (100-95%) the time, and mispronounces no words.	Speaks clearly and distinctly all (100-95%) the time, but mispronounces one word.	Speaks clearly and distinctly most (94-85%) of the time. Mispronounces no more than one word.	Often mumbles or cannot be understood OR mispronounces more than one word.
Appearance of Slides	All slides have a main font text and a color scheme that can be read by all audience members. All slides have text that is concise and easy to follow.	One slide does not have a main font text and a color scheme that can be read by all audience members. One slide does not have text that is concise and easy to follow.	Two slides do not have a main font text and a color scheme that can be read by all audience members. Two slides do not have text that is concise and easy to follow.	More than two slides do not have a main font text and a color scheme that can be read by all audience members. More than two slides do not have text that is concise and easy to follow.
Professionalism	Student remained professional throughout own presentation and was a respectful audience member through other presentations.			Student did not remain professional throughout own presentation OR was not a respectful audience member through other presentations.

Future Climate Change Projections – Oral Presentation Peer Feedback

Directions: For each presentation, provide one glow and one grow. A glow is a statement that tells the group what they did well, something you thoroughly enjoyed, etc. A grow is a statement that tells the group what could be improved, and a suggestion on how to improve it.

Rules: Feedback should be directed at the entire group, not a specific individual. Your feedback should be helpful and not judgmental.

Group (City): ______________________________

Glow: ____

____

Grow: ____

____

X. References - APA

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